Small Cells 2018

Abstract: This report provides comprehensive analysis of trends in Small Cell development, including 2G, 3G, 4G, and 5G. The report covers both indoor and outdoor units in many variations including integrated, RRH, and distributed DRS units. The report covers residential, enterprise, and carrier segments, and provide forecast of 5G small cells deployed in mid C-band and in the millimeter wave bands. The report includes shipment, revenue, pricing, and market share data.

Kyung Mun

April 2018

MOBILE EXPERTS

Small Cells 2018

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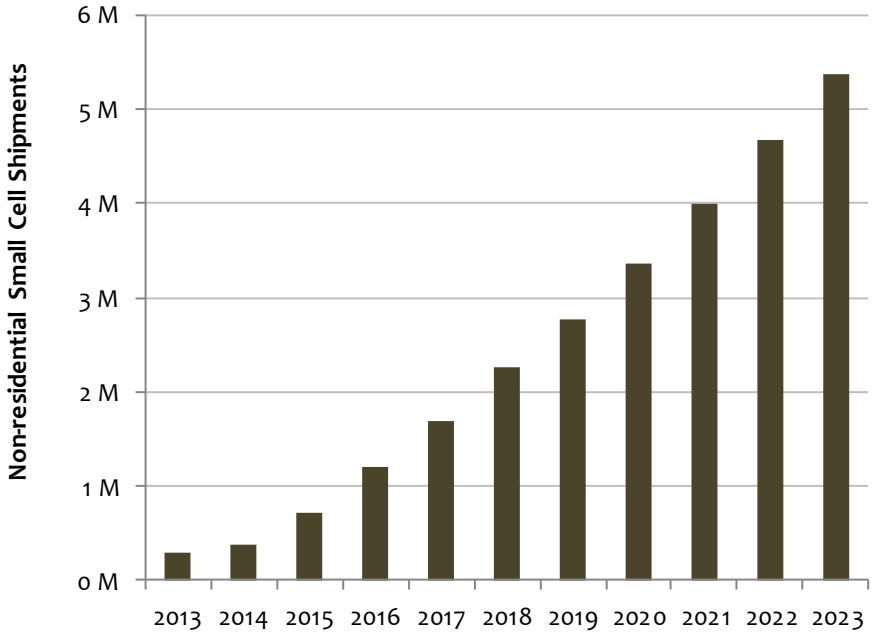
1 EXECUTIVE SUMMARY

The small cell market experienced a strong growth in 2017, with the volume shipment, excluding residential femtocells, growing 40% year over year. While the residential femtocell unit shipment declined in 2017, carrier deployments of indoor and outdoor small cells drove the overall market growth. The unit shipment of Carrier Indoor small cells grew 44% while the Carrier Outdoor grew over 60% from the previous year. These strong growth numbers resulted in the combined Carrier small cell total outstripping the annual Residential femtocell unit shipments for the first time. The growing carrier deployments bode well for the ecosystem suppliers as carrier units yield higher margin and higher ASP than the residential units. Excluding residential units, we expect the small cell volume to grow at over 21% CAGR during our forecast period from 2017 to 2023.



Source: Mobile Experts

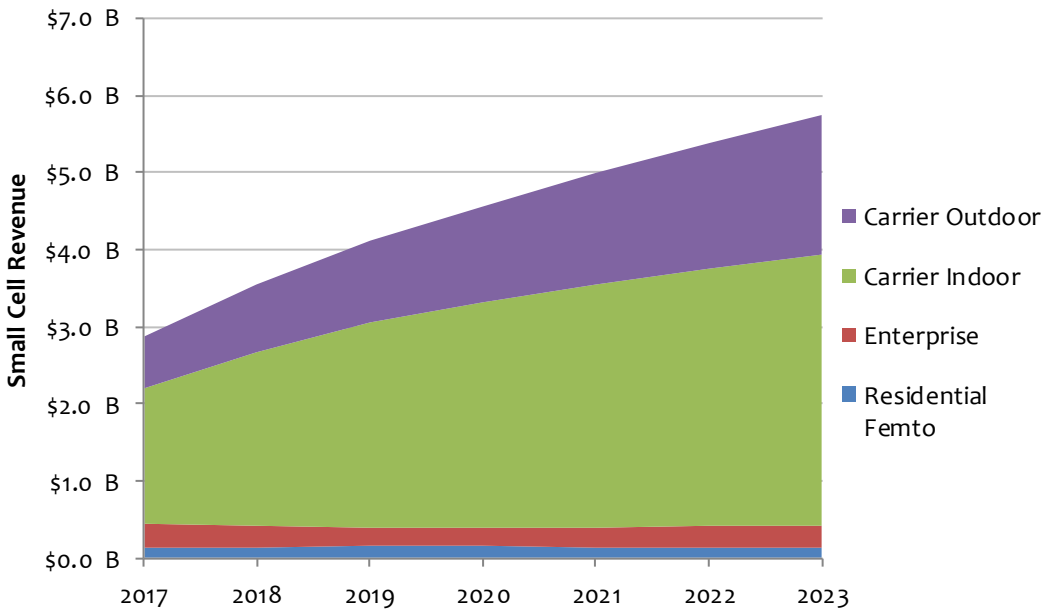
Chart 1: Non-Residential Small Cell Growth Forecast

Market trends point to another strong year in 2018. The second phase of Reliance Jio's network expansion will bring more small cell deployments along with macros. The operators in the USA are more aggressive about their network investment plans as inferred from stated CAPEX increases. As they jockey for "5G" market leadership, small cell investments are involved. Sprint will be certain to add more 2.5 GHz carriers as a part of its Macro expansion and more Magic Box small cells to surgically add capacity and coverage. T-Mobile is poised to leverage CBRS and LAA where needed while focusing on the 600 MHz macro rollout as a part of its "5G IoT" story. Verizon, meanwhile, continues to quietly leverage its residential/SOHO femtocells along with RRHs to densify network

while leverage its millimeter wave spectrum to launch 5G Fixed service in select locations. AT&T will selectively take advantage of LAA in its "5G Evolution" markets to tout high-speed services, but the scope of rollout is expected to be limited. Meanwhile, the Chinese carriers are planning for 5G rollout in the 3-4 GHz C-band. Regarding small cells, we expect the large installed base of CRAN-based DRS units such as Huawei's Lampsite and Ericsson's Dot to be upgraded to 5G starting in late 2019/2020.

With a growing list of available spectrum and technologies that enable access, the small cell product and applications are expanding. Beyond the traditional mobile operators, the interest in small cells is coming from cable operators, wireless ISPs, neutral host infrastructure providers, and some large enterprises. Flexible licensing rules like CBRS and unlicensed technologies such as LAA and MulteFire are opening new opportunities for small cell vendors in non-traditional applications and markets like private LTE, industrial IoT, and fixed wireless access.

In this year's report, we have included revenue contribution from DRS Hub units, not just the DRS radio units since they are integral part of the overall DRS solution. As a result, our revenue forecast is higher than last year's forecast. The small cell equipment sales grew 26% in 2017, rising to over $2.8B. By 2023, we forecast the market to double, reaching over $5.7B in sales revenue in 2023.



Source: Mobile Experts

Chart 2: Small Cell Revenue Forecast, 2017-2023

We forecast the Carrier Indoor segment to represent over 60% of the overall share during our forecast period as operators increasingly look to indoor applications as the mobile traffic demand mostly come from inside premises. Moreover, the higher band usage will

limit RF propagation from outside in, thus accentuating the need for more indoor small cells.

The initial 5G network investments in both the 3-4 GHz C-band and the above 20 GHz millimeter wave bands will be in Macro radio products. Even though the 5G millimeter wave, massive MIMO radio products will be compact and cover a limited RF coverage area relative to traditional Macros, they are considered "Macro" radios in our definition. In terms of 5G small cells, we expect most of them will be in the form of 5G DRS units that will be deployed mostly in China and some in APAC. The initial 5G millimeter wave, massive MIMO products that meet our "small cell" definition will be very limited as most initial 5G RRHs will be high EIRP units for macro densification in core urban areas in city centers.

2 MARKET ENVIRONMENT

The small cell market continues to grow as operators ramp up small cell deployments to "fill in" coverage and capacity "holes" left behind after the initial LTE macro coverage rollout. The market activity across both indoor and outdoor deployments is strong. As the mobile networks get denser, the siting challenges are enabling new small cell architectures like wireless relay and strand mount for example. Beyond the licensed spectrum, the use of shared and unlicensed spectrum via CBRS and LAA is opening new market opportunities like neutral host in-building wireless, MVNO offload, and fixed wireless access to name a few.

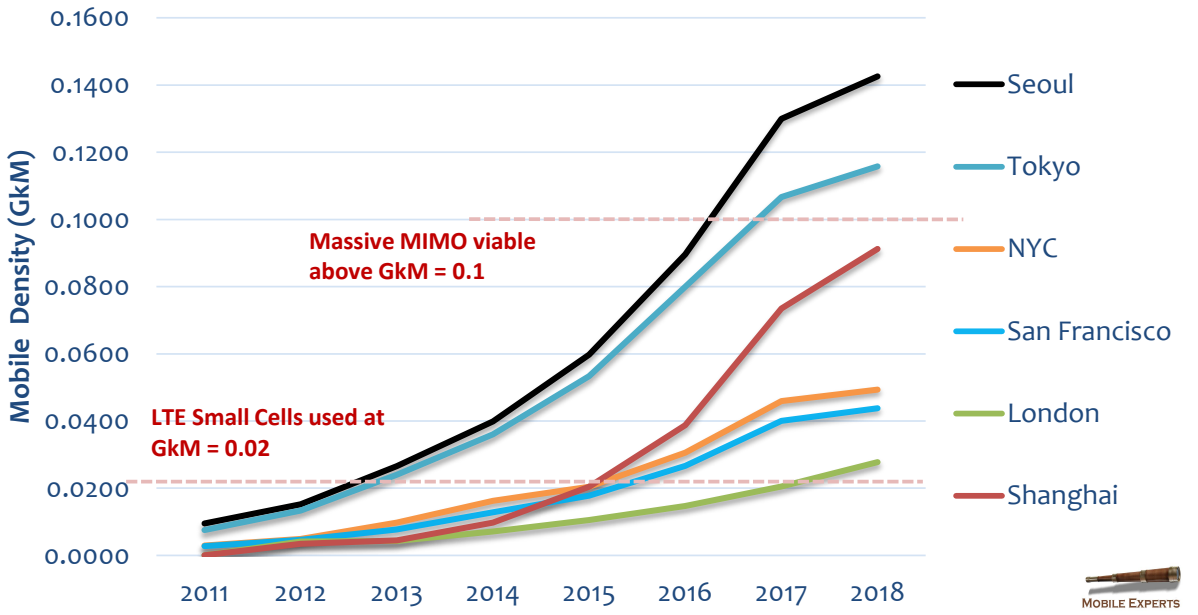
The industry transition to 5G is providing a tailwind momentum in the near term as regulatory agencies are more eager to open up more spectrum and appears poised to help ease infrastructure challenges. The new spectrum availability in high bands and flexible licensing rules around CBRS, in particular, are bringing new players and new business opportunities for the small cell product and wireless infrastructure vendors.

Demand Drivers

The fundamental demand pillars for continued small cell growth are simply:

1. Mobile traffic growth and usage; and,
2. Use of higher spectrum bands

The mobile data traffic growth over the years has been remarkable. Based on historical data, it appears that there is insatiable demand for mobile data use. Even during the recent global recession ten years ago, the mobile data usage didn't falter. When LTE network was built out in some markets, the demand has simply skyrocketed – e.g., Reliance Jio in India reported a five-fold increase in mobile data consumption. According to Cisco, the global mobile data traffic grew over 60% in 2016. The density of mobile data traffic has been going up in many markets and core urban cell sites. As the smartphone penetration grows, we have observed that this mobile data traffic density, which we monitor under GkM (**G**bps per **k**m squared per **M**Hz of licensed spectrum) parameter, has been growing and spreading to cell sites beyond the urban core.



Source: Mobile Experts

Figure 1. Mobile Density (GkM) Trend Worldwide

This "spreading" of mobile traffic density will continue to fuel network investment on both Macro and small cells.

Another key demand driver of small cell growth has been the fact that additional spectrum that operators will deploy in the future especially as they consider 5G services are higher band spectrum beyond the core 1-3 GHz spectrum that has been foundational in 2G/3G/4G network services around the world. As these core spectrum bands are tapped out with existing services, regulatory bodies are opening up higher bands in the 3-4 GHz and even the ultra-high millimeter wave bands in 27-40 GHz. As operators look to deploy networks at these higher bands, there will inevitably be "holes" which will need to be "filled in" with small cells for seamless coverage.

New Spectrum – Licensed, Unlicensed and Shared

Beyond the core 1-2 GHz spectrum for Macro network services, small cell deployment in the sub-3 GHz has been prevalent in the recent years. As mobile operators start their 5G commercialization plans, regulators are opening up even more bands under licensed, shared, and unlicensed paradigms. Below is a list of additional spectrum that is coming available for operators as they consider optimal ways to build out their networks using different spectrum bands, technologies, and Macro vs. Small Cell base stations.

Spectrum	Duplex Mode	Bandwidth	Channel Bandwidth	Access Technology
3300 – 3800 MHz	**TDD**	**500 MHz**	**5..20 MHz**	**5G NR**
3450 – 3550 MHz (US)	TDD	100 MHz	?	? (possibly CBRS)
3550 - 3700 MHz (US)	TDD	150 MHz	10 MHz	CBRS
3300 – 4200 MHz	**TDD**	**900 MHz**	**10..100 MHz**	**5G NR**
3700 – 4200 MHz (US)	TDD	500 MHz	?	?
4400 – 5000 MHz	**TDD**	**600 MHz**	**40..100 MHz**	**5G NR**
5150 – 5850 MHz	**TDD**	**~650 MHz**	**20..160 MHz**	**Wi-Fi / LAA / MulteFire**
24.25 – 27.5 GHz	**TDD**	**3250 MHz**	100 MHz (estimate)	**5G NR**
24.75 – 27.5 GHz (China)	TDD	2750 MHz	100 MHz (estimate)	5G NR
24.25 – 27.5 GHz (EU)	TDD	3250 MHz	100 MHz (estimate)	5G NR
26.5 – 29.5 GHz (under consideration)	**TDD**	**3000 MHz**	100 MHz (estimate)	**5G NR**
27.5 – 28.35 GHz (USA)	TDD	850 MHz	100 MHz (estimate)	5G NR
26.5 – 29.5 GHz (Korea)	TDD	3000 MHz	100 MHz (estimate)	5G NR
27.5 – 29.5 GHz (Japan)	TDD	2000 MHz	100 MHz (estimate)	5G NR
37 – 40 GHz (under consideration)	**TDD**	**3000 MHz**	100 MHz (estimate)	**5G NR**
37 – 42 GHz (USA)	TDD	5000 MHz	100 MHz (estimate)	5G NR
37 – 42.5 GHz (China)	TDD	5500 MHz	100 MHz (estimate)	5G NR
40.5 – 43.5 GHz (EU)	TDD	3000 MHz	100 MHz (estimate)	5G NR

Source: 3GPP, Mobile Experts

Note: GREEN – licensed spectrum (or likely); YELLOW – shared spectrum; BLUE – unlicensed spectrum

Figure 2. New Spectrum for Macro and Small Cells

The new spectrum available for small cell deployments can be grouped into three band ranges:

1. 3 GHz "C-band" (including the 3.5 GHz CBRS shared band)
2. 5 GHz unlicensed band
3. 27-40 GHz millimeter wave bands

The rich abundance of new spectrum available for Macros and Small Cells offers diverse opportunity for operators and vendors to innovate around small cell products and deployment scenarios. Based on R&D activities of major vendors and expectations of key operators, the initial 5G deployments will be in the 3-4 GHz C-band in China and APAC. North America will follow once the spectrum rules around 3.7-4.2 GHz are settled. Most

outdoor deployments will be high-power Macros while the indoor deployments will use DRS small cell architecture, especially in China. The LAA small cell deployments will mostly be in North America and other regions where operators have limited licensed spectrum holdings. LAA small cells will mostly be deployed in urban core and in large stadiums where high-density usage requires a dense network with additional spectrum to increase capacity. Finally, the initial use of the millimeter wave bands will mostly come from high power RRH deployments as a part of Macro densification. Most initial products are high power (greater than +52 dBm EIRP) units which fall in the Macro category in our forecast.

New Players and New Market Opportunities

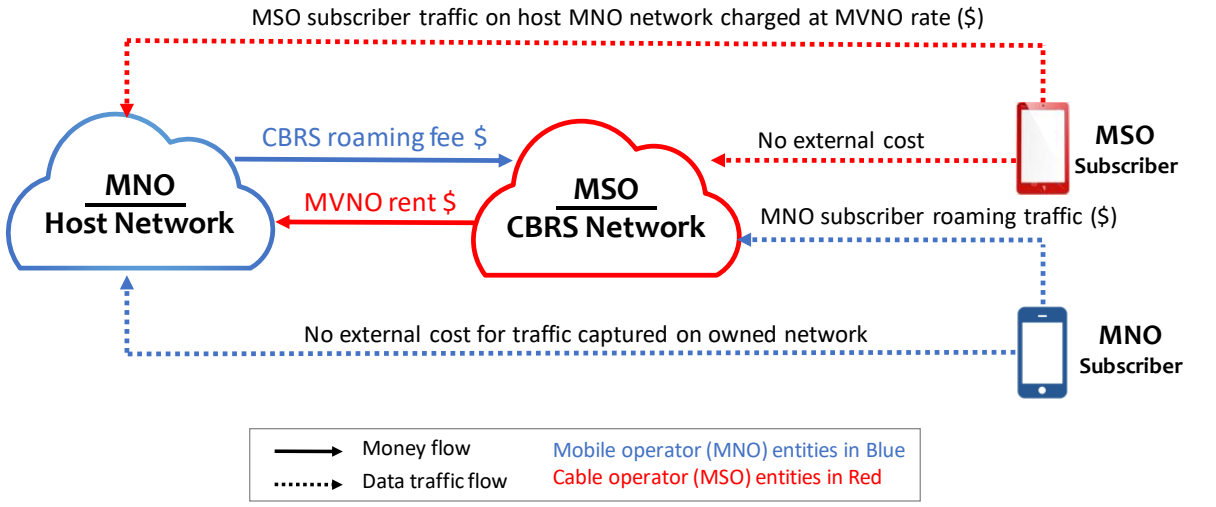
The new shared and unlicensed spectrum regimes and technologies (i.e., CBRS, LAA, and MulteFire) are opening new market opportunities for non-mobile players like cable operators, enterprises, tower companies, and other neutral host providers to possibly partake in mobile network services through the "cheaper" spectrum options. For cable operators who have market-leading positions in video and fixed broadband businesses, the "cheaper" spectrum alternatives offer a possible entry point to get into the mobile business. For tower companies, who are already "neutral" infrastructure suppliers to the mobile operators, the new spectrum opportunity in the CBRS band offers a pathway to extend infrastructure sharing up a notch to providing neutral radio services to the mobile operators. For certain enterprises, having a private LTE network through CBRS, and possibly augmenting it with LAA, offers full control over enterprise-critical applications like industrial IoT / automation applications. Here are some interesting market opportunities that new spectrum along with small cells can enable for the new players.

Cable MVNO Offload

Cable operators today partake in mobile business through MVNO arrangements with mobile operators. While it is a quick and relatively low-CAPEX way to enter the market, it is not a satisfying nor profitable one as cable operators incur continuous MVNO expenses as a "renter" to the host mobile operators. CBRS is a good alternative for cable operators to build own LTE network with presumably cheaper "shared" spectrum. The shared CBRS spectrum in smaller geographical licensing areas is expected to yield lower-cost spectrum than traditional licensed spectrum which has historically cost billions of dollars in key metro markets.

The LTE network built on the CBRS band is a better offload network than Wi-Fi. LTE service across both host macro network and owned CBRS small cell network may simplify network integration efforts and will likely result in more predictable user experience than offloading to Wi-Fi. The cable operators can capture additional subscriber mobile traffic on the 3.5 GHz band with LTE, in addition to 2.4/5 GHz bands with Wi-Fi, to reduce the amount of charged traffic going over to the host mobile operator network.

The profitability of a MVNO business case is heavily dependent on lowering the amount of traffic going over to the host mobile operator network. Since an MVNO pays a mobile operator for traffic going over the host operator's network, higher subscriber usage directly translates to higher network expenses. Hence, for the cable operators, this means offloading subscriber traffic over to owned networks as much as possible.



Source: Mobile Experts

Figure 3. Cable MVNO/CBRS Offload Business Model

The cable MVNO offload strategy can be extended to a new business model. It involves a "swap" arrangement with the host mobile operator to allow mobile operator (MNO) subscribers to roam onto the cable operator's CBRS network in exchange for a lower MVNO terms. Having owned LTE-based network in strategic places where most of subscriber traffic is generated or consumed, affords additional optionality for the cable operators. Besides reducing MVNO expenses through traffic offloading, the cable operators can negotiate for better MVNO terms involving a potential "swap" deal.

Fixed Wireless Access

More than 28 million Americans still use DSL, power line, or satellite Internet service providers because they can't get decent broadband services to their homes.[1] Fixed wireless access (FWA) presents an opportunity to change the "underserved" rural and suburban markets, improving data speed for these 28 million homes. Broad licensed spectrum below 4 GHz is difficult to find, and all available scraps have already been auctioned to the major telecom carriers for LTE operations. As a result, most Wireless ISPs who are sometimes the only broadband provider in some rural communities, use unlicensed 5 GHz spectrum for broadband access. CBRS spectrum sharing offers additional spectrum resource for these Wireless ISPs and other new entrants in this space.

The concept of spectrum sharing works much better than exclusive licenses for rural FWA. In a rural area, a local entrepreneur can set up a CBRS network based on fiber and wireless backhaul to a central location, with several subscribers sharing each CBRS access point.

Rural customers are not the only opportunity here. Many urban and suburban customers in the United States are stuck with only a single choice for broadband access, and the monopoly status of these providers results in predictably horrible service. Consistently, surveys conducted by Consumer Reports have rated Comcast, Time Warner Cable (now Charter), and Charter among the "bottom dwellers in overall customer satisfaction." In short, the pent-up demand for alternative broadband services is strong but fragmented, based on various levels of service and regional market competition.

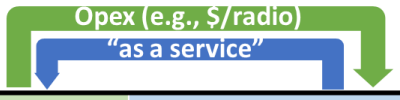
The FWA opportunity is not well suited to a one-size-fits-all solution like mobile where a nationwide coverage and seamless service is expected. FWA is a regional business and can be addressed by small companies, or by a national company that has many tools in their box. The CBRS spectrum sharing allows flexible spectrum sharing without heavy up-front expense associated with traditional licensed spectrum auctions where large spectrum blocks can go for billions of dollars in key metro markets. By parsing into smaller chunks, the spectrum can be made more affordable for smaller players.

In-Building Wireless Neutral Host

Stadiums, large hotels, and airports in the USA are already generally outfitted with DAS systems because the DAS can provide a "neutral" communications platform, meaning that any mobile operator can utilize the coverage for its subscribers. However, the existing DAS infrastructure is limited to 3G in some cases. Continuous upgrades with LTE and higher order MIMO will drive many large DAS venues toward very expensive upgrades, as new cabling, amplifiers, and antennas will be needed.

[1] FCC Internet Access Service report, June 30, 2016

At the same time, many smaller buildings in the US market have not been equipped with DAS infrastructure because the high cost of "full" DAS makes an ROI problematic for the operators. Verizon and AT&T feel that small buildings are not worth the effort to coordinate and deploy a DAS. CBRS infrastructure offers a good alternative here. Instead of expensive DAS equipment with high capacity and independent radios for each operator, a CBRS network can function independently of each operator's spectrum, and offer shared access for everyone.



	Enterprise / Venue	Neutral Host Network (NHN) Service Provider	Mobile Network Operator (MNO)
Operations		• Network management • RAN optimization • Network maintenance • Seamless MNO interoperability • Charging	• KPI monitoring • Seamless NHN interoperability
Core Network *for local networks*		• Core networking • SAS coordination • Spectrum licensing • MNO network integration • LBO/enterprise application integration	
Radio Access Network (RAN) *at local venues*	• RF design and commissioning • Radio purchase and installation		

Source: Mobile Experts

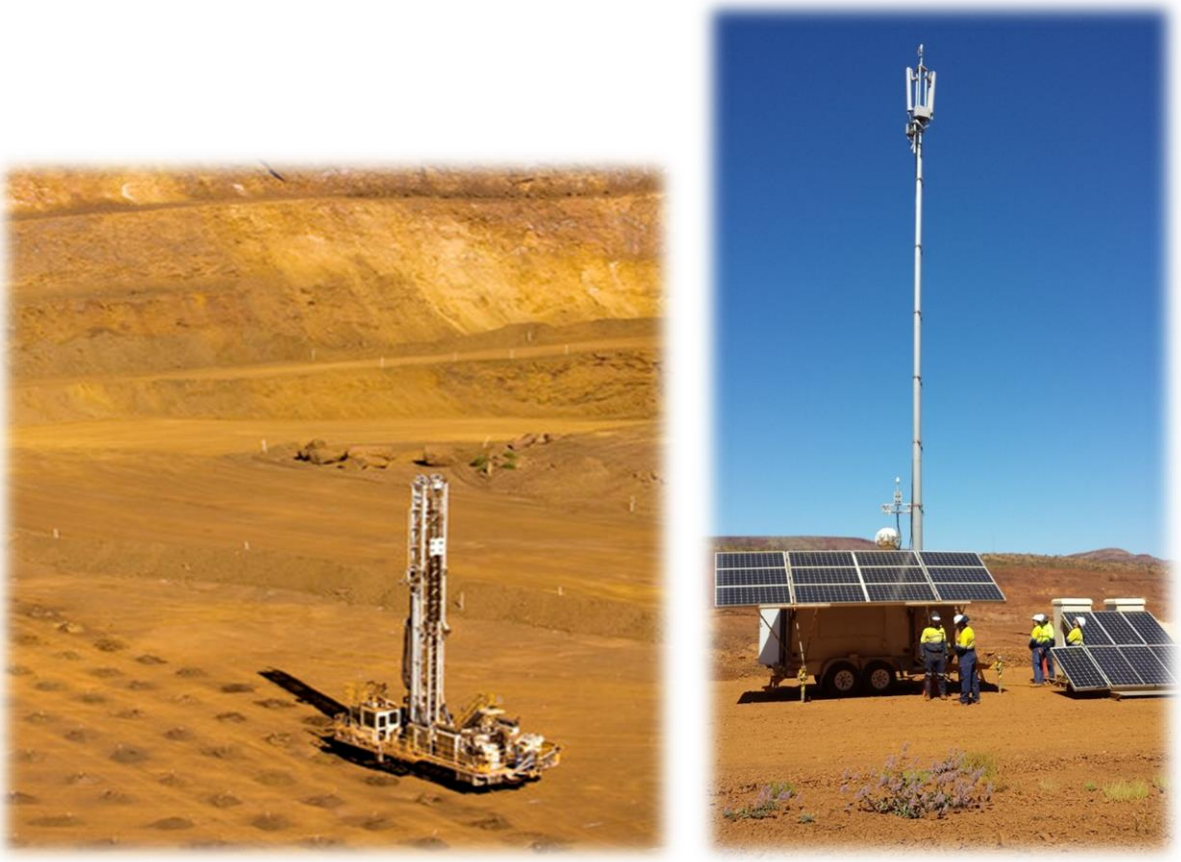
Figure 4. Neutral Host Service Provider Business Model

This is not a magic solution, and some operators will not like this approach because of the loss of control over the user experience. In particular, operators that take pride in the quality of their networks do not want to relinquish control to a neutral host company such as Crown Castle, Extenet, or others. The end user will continue to think that the voice and data services inside the building are offered by the major carrier….so any loss in quality will hurt the carrier's reputation. So, there are challenges with gaining acceptance and cooperation from the mobile operators, but this solution has the elegance of low cost shared infrastructure and the ability to provide seamless coverage in millions of buildings across the United States.

Private LTE and Industrial IoT

As industrial enterprises rely on broadband connectivity more, the opportunity for private LTE-based communications networks is starting to grow. Here are some Private LTE use cases that have arisen during the past three years:

- Rio Tinto has 15 mines, four shipping terminals, and its own railway in Western Australia. The company uses autonomous mining and transport in a great deal of their network based on a highly developed private LTE network. The Rio Tinto network was launched in August 2013 with four solar-powered trailers that are constantly moved around as mining operations literally change the landscape and terrain around them. Other mining companies such as BHP, Glencore Xtrata, Vale, Freeport McMoRan, and Fortescue are following the lead of Rio Tinto with their own networks and automation. Rio Tinto uses licensed LTE spectrum, and some of the others plan to use 5 GHz unlicensed (MulteFire). American mining companies can be expected to use CBRS-based LTE because of high RF power limits and cheap availability of products in the 2019 timeframe.



Source: Rio Tinto

Figure 5. Rio Tinto's Automated Drill and LTE Infrastructure

- Industrial operations are a large potential market. As one example, DSME (Daewoo) and SHI (Samsung) operate automated shipbuilding operations in Korea where LTE networks control thousands of welding machines for higher quality welding joints. Where unlicensed wireless technologies are replacing Fieldbus or

Ethernet wires in some factory settings, larger industrial operations will need LTE for longer range connectivity with low latency and high reliability.

- GE Digital is investing in a trial network with Nokia and Qualcomm in the CBRS band, in its Predix lab in California. This type of American investment in manufacturing and industrial operations will translate into growth momentum in CBRS-based private LTE.
- Transportation operations are often discussed for Private LTE networks. Many automated cranes and ground vehicles use RFID technology today, but LTE could give them a boost in range, speed, and flexibility. In addition, LTE could support video operations which would improve safety and oversight of these massive moving structures. CBRS systems can be installed for a locally secured network, without any fees to mobile operators for large data streams such as video.

Source: Qualcomm

Figure 6. Use of Private LTE in Port Operations

- Remote operations need automation as well. Shell has introduced a "Sensabot" to conduct routine checks on remote equipment in remote or dangerous locations, dramatically lowering the cost of monitoring oil & gas exploration and drilling sites. One additional aspect of this kind of automation is that often the Oil & Gas industry has locations with potentially explosive gases and other safety hazards for human technicians.
- Point-of-Sale terminals present challenges in security, portable operation, data speed, and reliability. In large venues, portable POS terminals are best implemented on a private network for a secure and predictable connection, every time.
- In addition to all of the above, Public Safety is another key business area for Private LTE infrastructure suppliers. In some cases (such as FirstNet), the network is arguably not a "Private LTE" network since the infrastructure can be made available for the general public's broadband use. However, to the extent that these networks are funded by public safety agencies, we count them as a Private LTE network. The growing need for video data in firefighting and law enforcement

is now driving much stronger growth in public safety investment for wireless infrastructure, and LTE is quickly moving to the top of the list of "known technologies" that are trusted by key agencies.

Today, the Private LTE market is not as big as other analysts claim. After asking several vendors for specifics, we can only identify a few real installations of Private LTE networks worldwide. One challenge for Private LTE is the need to coordinate on spectrum with the mobile operators that own exclusive spectrum rights. Rio Tinto has the wherewithal to negotiate a deal with Telstra….but most manufacturing plants, retail malls, and public safety agencies would not think of trying to sublease licensed spectrum.

CBRS can change the dynamics, to open up an easy-to-use product line in which a vendor can simply sell a solution to the enterprise. While this model only works in the USA, the MulteFire equivalent could work on a global basis in the same way.

Regulatory Environment

With 5G commercialization just around the corner with many operators claiming 5G commercial launch in 2019, the regulatory environment has become more dynamic. Vendors and operators are pushing to have more spectrum in the "mid" band around 3-4 GHz and the millimeter wave band in 27-40 GHz.

The Chinese government, in particular, is pushing very aggressively to open up spectrum at 3.5 GHz and 4.9 GHz for 5G networks. Other governments worldwide are working to harmonize spectrum as much as possible in 5G bands.

With operators and regulatory agencies in China, Japan, and Korea pushing to open up potentially 100 MHz per operator in the C-band, FCC is feeling the heat to expedite spectrum rules around the 3.5 GHz band, and the 3.7-4.2 GHz band. In the current political climate with possible trade war and a government intervention of possible technology mergers, the "5G" race has taken on a national significance. According to Reuters, the Trump administration even suggested building a national 5G network as an option for national cybersecurity.[2] In this environment, regulators don't want to be seen as an inhibitor to national interest of achieving global first in 5G network launch.

More Spectrum

Regulators around the globe are actively working to open up hundreds of MHz of spectrum in the C-band and thousands of MHz in the millimeter wave band. Through 3GPP standardization and ITU's WRC discussions, the global harmonization of 5G spectrum is coming together with the 3.5 GHz C-band as a common baseline worldwide. Meanwhile,

[2] https://uk.reuters.com/article/us-usa-trump-5g/trump-security-team-sees-building-u-s-5g-network-as-option-idUKKBN1FH103

each regional regulators are working towards opening up wider channel spectrum in the "mid" band below 6 GHz:

- Japan: The Japanese Ministry of Internal Affairs and Communications (MIC) has recently changed its 5G licensing rules to open up more competition between its three major carriers and other non-telecom players. We expect MIC to grant spectrum licenses over the next few months, in preparation for the Tokyo 2020 Olympics. MIC has not made an official announcement on the spectrum to be licensed, with possibilities ranging from 3600-4200 MHz and 4400-4900 MHz. The most credible reports from Japanese operators expect that the 4.5-4.8 GHz band will be allocated for 5G in blocks of 100 MHz each.
- Korea: South Korea will begin a 5G auction in June 2018, with about 100 MHz for each of the three major carriers in the 3400-3700 MHz band. This is a significant acceleration of the timeframe, as previous announcements aimed at licenses in 2019.
- China: The Ministry of Industry and Information Technology (MIIT) has set aside the 3.3 to 3.6 GHz band, as well as 4.8-5 GHz. The band from 3.6 to 4.2 GHz may be introduced later. Rumors indicate that China Mobile is likely to get the 4.8-5 GHz block, while China Unicom and China Telecom are likely to get spectrum in the 3.3 to 3.6 GHz range as well as authorization to use the 700 MHz or other 900 MHz-2.5 GHz spectrum for 5G NR.
- Europe: Various countries in Europe are lining up in the 3.4-3.8 GHz band with 5G spectrum plans. Ireland, Italy, Spain, and Finland have designated bands within this range as possible upcoming licenses.
- United States: The bands between 3.3-3.5 GHz and 3.7-4.2 GHz are possibilities for 5G allocation, but are also heavily sought after by Google and other unlicensed users. No decisions have been made by the Federal Communications Commission on these bands yet, so the only C-band spectrum possible in the USA is the 3.55-3.7 GHz shared spectrum, which will be licensed over the next 6-12 months through a new Priority Area Licensing process. It's not clear whether US operators would deploy LTE or 5G NR radios in this band.
- Note that ZTE and Huawei have demonstrated asymmetric use of 5G spectrum, with 3.5 GHz used as the downlink band and 1.8 GHz or other bands used for uplink. The configuration of LTE would be based on TDD, despite the separate uplink and downlink bands. Support for this proposal is growing because it could benefit the link balance greatly.

… and in the millimeter wave band above 20 GHz:

- USA: The focus for 95% of development efforts today is at 28 GHz, with active commercial deployment taking place in the 27.5-28.35 GHz band in the USA with Verizon Wireless. American operators also have licenses to FDD spectrum at 24

GHz, as well as TDD spectrum at 37-40 GHz, so we expect deployment of 5G fixed-wireless services in these bands as well.

- In Korea, the entire 26.5 – 29.5 GHz band is available for 5G services and is expected to be auctioned in June 2018 (probably 1 GHz to each of the three operators).
- Japan: Operators are conducting trials at 27.5-29.5 GHz. With the high density of the Japanese network, we're expecting the C-band deployment to be followed by hotspot 28 GHz deployment in the 2022-2023 timeframe.
- China: The 24.75-27.5 GHz band and 37-42.5 GHz bands are under consideration by the MIIT for 5G trials. The next set of decisions will take place after some trial results come available.
- Europe: Individual countries such as Sweden are expected to award licenses at 28 GHz over the next two years. Also, European regulators have designated a "pioneer band" at 24.25 – 27.5 GHz as a 5G band, and another likely band at 40.5-43.5 GHz.

Small Cell Siting

In addition to making available more spectrum, regulators have been looking to streamline the wireless infrastructure siting approval process. Unlike in China where telecom infrastructure rulemaking is more centralized and streamlined, infrastructure regulatory procedures can be excruciatingly slow as the final approval is conducted at the local level. For a mobile operator looking to deploy thousands of small cells in a market will need to deal with the individual municipalities. Timely access to siting for small cell deployments have become an important issue for the industry. Wireless infrastructure trade groups and infrastructure companies such as Mobilitie, Crown Castle, and Extenet, along with major mobile operators have many petitions and lobbying efforts to ease the regulatory approval process for access to the public right-of-ways. Recently, the group won a victory when the FCC approved an order to streamline small cell review process and excluded small cell sites from historical preservation and environment reviews.[3] While the FCC's action is a welcome news for the industry, the major operators and infrastructure suppliers will still need to work closely with cities and other agencies to streamline the siting and deployment procedures. For example, Verizon's Smart City initiative with the City of Boston in concert with its 5G fixed wireless trials is a good model.

As predicted, the industry lobbying efforts at the state and federal levels have yielded a positive outcome in the form of the FCC's *Wireless Infrastructure Streamlining Report and Order*.[4] Also, the municipalities and infrastructure service providers need to work out reasonable rate fees for site lease. Small cells will be placed in close vicinity to residences and businesses to enable faster mobile communications. It is in common interests of both the municipalities and infrastructure providers to enable this, and we believe, 'best

[3] https://transition.fcc.gov/Daily_Releases/Daily_Business/2018/db0301/DOC-349528A1.pdf
[4] https://transition.fcc.gov/Daily_Releases/Daily_Business/2018/db0301/DOC-349528A1.pdf

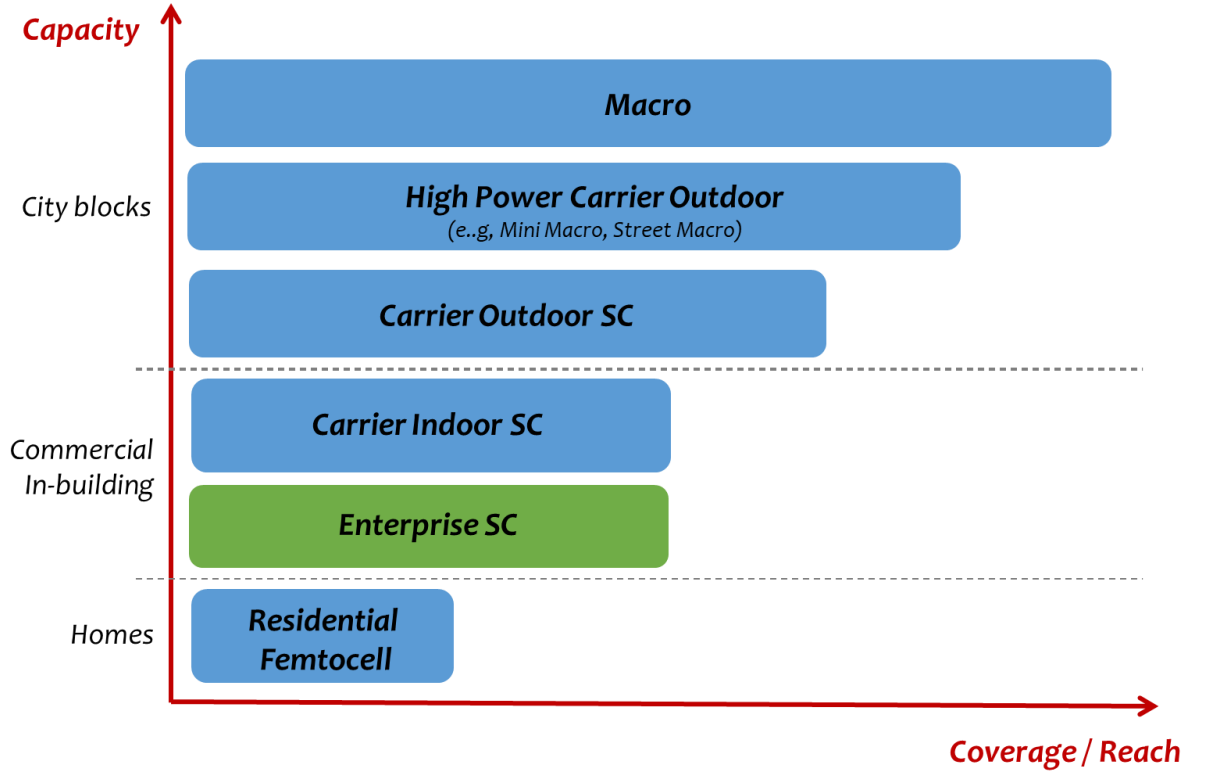
practices' will be worked out in the next couple of years. Some local governments have resisted this regulatory action, with California notably rejecting the FCC guidelines. However, we believe that the demand for mobile data will quickly create pressure to accept small cells, and California will not be able to justify ongoing resistance. The consumer demand for mobile services is strong, so this will work itself out in the end.

3 TECHNOLOGY BACKGROUND

The "small-ness" of Small Cells in terms of size and cost, and multiple deployment models that are possible relative to large monolithic Macro base stations, continues to yield expanding small cell variants and architectures. Expanding spectrum options in higher licensed, shared, and unlicensed bands in the C-band (3-4 GHz) and even the millimeter wave bands (28-40 GHz) is opening up new market opportunities and technology choices.

Small Cell Variations

Most major mobile networks are heterogeneous networks or HetNets with layers of macrocells and small cells supporting multiple generations of 2G, 3G, and 4G. This layered network topology is a result of operators' push to provide seamless services across multitude of client devices and subscribers. As the mobile traffic demand grows especially in urban core environments, major operators are increasingly leveraging outdoor and indoor small cells to augment network capacity where needed to alleviate network demand on Macro network layer. While mobile operators are primary stakeholders in RAN deployments, some large enterprises and managed service providers are making strategic small cell investment for in-building wireless needs.



Source: Mobile Experts

Figure 7. Small Cell Types by Business Model

Hi-Power Carrier Outdoor

One of the key innovations of Small Cells is the fact that the radios are becoming small enough to place on sites other than the typical macro cell towers while providing output power that are similar to Macro base stations. Nokia and some smaller vendors have found success with Hi-Power Carrier Outdoor Small Cells over the past several years. These "Macro-like" small cells have been hugely successful in filling weak coverage and performance areas where it's too costly to deploy Macros. With size dimensions around 300 mm (W) x 250 (H) x 150 (D), the Hi-Power Carrier Outdoor Small Cells have become popular "coverage and capacity" solution for many operators seeking low TCO solution as they offer lower and easier site acquisition than typical Macros. While older-generation of Hi-Power Carrier Outdoor Small Cells offer 2x20W radios, we expect some to offer 4T4R variation to offer higher-capacity radio solutions.

Source: Nokia

Figure 8. Hi-Power Carrier Outdoor deployment in urban environment

With the availability of the millimeter wave bands and 5G, some major vendors are starting to introduce 5G baseband integrated, massive MIMO radios. Ericsson's Street Macro falls in this category. With 500 mm height, it is taller than traditional 2x20W Hi-Power Carrier Outdoor products that we have seen in the past. With our definition of "Hi-Power Carrier Outdoor Small Cells" within the EIRP of +52 dBm, Ericsson's Street Macro is categorized as a Macro in Mobile Experts' definition. We have seen some major vendors starting to categorize massive MIMO, millimeter wave (28-40 GHz) band "small cell" products with EIRP of +53 dBm or higher. While we do expect to see some millimeter wave, Hi-Power Carrier Outdoor Small Cell products to come to market in the next couple of years, most of these products currently fall into the "Macro" category by our current definition, i.e.,

massive MIMO EIRP greater than +52 dBm. (Please refer to our *5G Research* series for a forecast of these 5G units.) We will monitor the market development over the next couple of years and may change our definition of massive MIMO based Small Cell products based on market acceptance of what EIRP constitutes "Small Cell" vs. "Macro."

Carrier Outdoor Small Cells

The Carrier Outdoor small cells come in multiple variations such as: 1) an integrated "all in one" unit -- with baseband plus radio plus antenna, or an integrated form factor with connectorized ports for external antenna; or 2) Low Power RRH - with just radio portion with integrated antenna to be used in CRAN context. Mobile Experts defines a Carrier Outdoor small cell with RF power of 300 mW to 5 W per antenna. Generally, the Carrier Outdoor small cells are often refer to as "Microcells" which can easily be installed or disguised due to their small size.

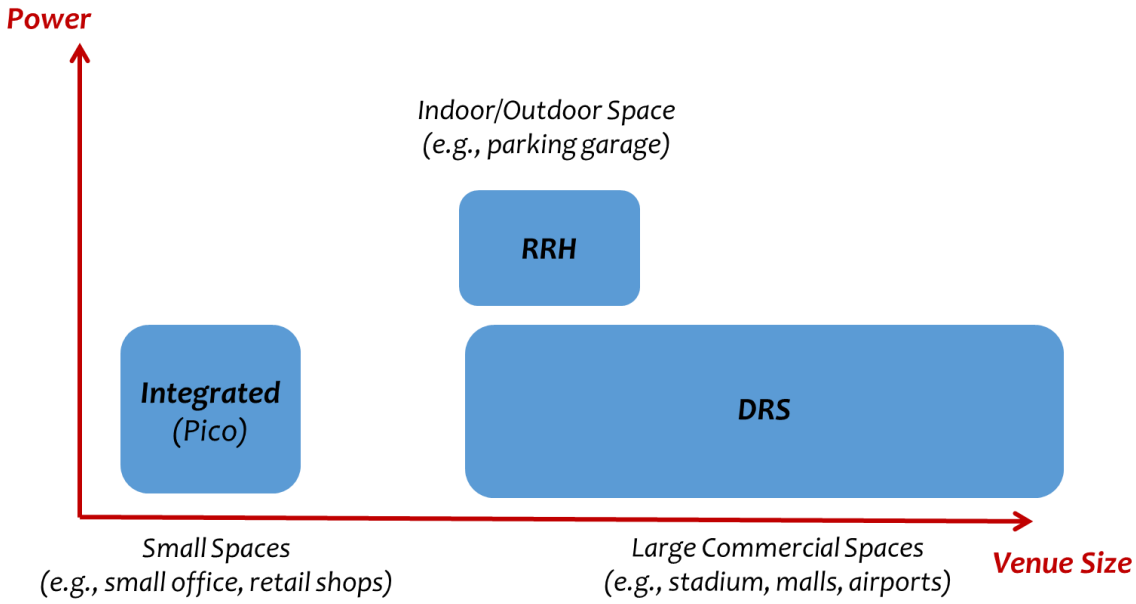
Source: Ericsson (at MWC 2018)

Figure 9. Carrier Outdoor Small Cells on pole (center) and on cable strand (upper right)

Carrier Indoor Small Cells

Carrier Indoor Small Cells provide a high-capacity solution for key public venues like transportation hubs such as airports, conference centers, malls, and other major indoor venues where RF coverage is lacking, or additional network capacity is needed. While DAS is a popular technology solution for multi-operator venues like large sporting stadiums, Carrier Indoor Small Cells offer cost-effective solution when operators are making direct network investments which is common in the China and APAC regions.

Mobile Experts categorize Carrier Outdoor and Carrier Indoor Small Cells by architecture, namely Integrated vs. RRH. In the Carrier Indoor Small Cell segment, we further classify RRH into Distributed Radio System (DRS) architecture in which a RRH "hub" unit drives multiple remote radio units "deeper" within a building. Huawei's LampSite and Ericsson's Radio Dot are representative product solutions of the DRS architecture.



Source: Mobile Experts

Figure 10. Carrier Indoor Small Cell Types by Use Case

Over the past several years, major Chinese operators have shown a clear preference for the DRS architecture. DRS has been used heavily for larger venue indoor deployments such as airports, stadiums, and malls to scale coverage and capacity using structured Cat5/6 cabling or fiber. With each remote radio unit typically supporting 2x100mW output power in a 2T2R configuration, each radio unit can cover 5,000-10,000 square feet of space. For higher operating frequency band, some vendors offer higher output power radio units to account for the RF signal attenuation at the higher bands. With 5G NR deployments in the 3-4 GHz C-band, each radio unit in DRS systems will likely support higher MIMO configurations (4T4R) and output power (250 mW per stream).

For smaller commercial spaces like small offices and retail shops, compact "all-in-one" Integrated Carrier Indoor small cells, sometimes refer to as "Picocells," offer a cost-

effective coverage and capacity solution. While today's Carrier Indoor Small Cells typically support 2x250 mW output power, we expect to see 4T4R versions in the future as more devices that can take advantage of higher MIMO streams become more pervasive in the marketplace.

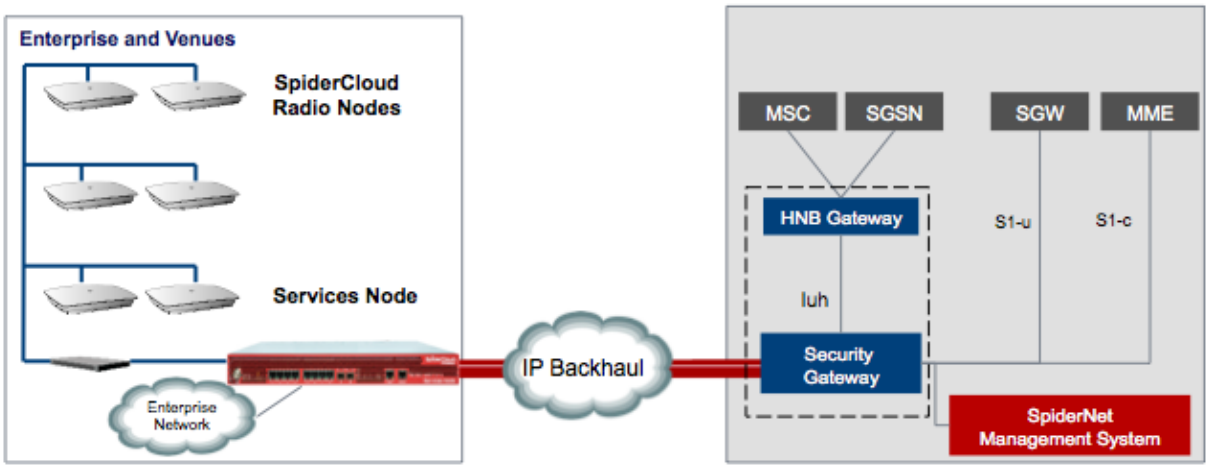
Source: Nokia

Figure 11. Carrier Indoor Small Cell deployments

For certain "hybrid" indoor/outdoor spaces like public garage locations adjacent to large public buildings like stadiums, operators sometimes deploy higher-power RRH units alongside DRS to extend coverage. Both RRH and DRS architectures can be driven by remotely located baseband processing pools, so the difference is generally in the configuration of the RF section where an RRH unit has higher power, and a DRS unit is configured for several low-power transmitters.

Enterprise (Controller-based) Small Cells

Enterprise applications increasingly use a local controller to coordinate multiple small cells, to assist in local breakout, caching of local data, integration with the company's server or LAN, and to facilitate LTE-Advanced features such as CoMP and eICIC. This approach facilitates deployment of the radio units throughout the building very quickly because the controller box in the IT closet feeds Cat-5 or Cat-6 cabling which can be deployed very quickly over the ceiling tiles in many office buildings.



Source: SpiderCloud

Figure 12. An example of a controller-based architecture for small cells

The controller-based approach works best for larger buildings, where multiple radio nodes are deployed that may overlap with each other and where some coordination between radio nodes is important. Over time, we expect the controller box to become a platform for the enterprise to run value-added services such as instant messaging or other applications for employees throughout the building.

Residential Small Cells

The Residential small cell or femtocell has become a forgotten category over the past several years, as operators and vendors focus on high-value Small Cells with high-capacity and deployment complexities. While the total market opportunity is certainly much smaller than the Carrier Outdoor and Carrier Indoor varieties, the Residential Femtocells continue to provide a steady market opportunity, especially for non-Tier 1 infrastructure vendors. While the volume opportunity is high, the revenue opportunity is relatively low. Another unfortunate aspect of this market segment is that Residential small cells is highly price-sensitive to the operators; hence, the margin is low.

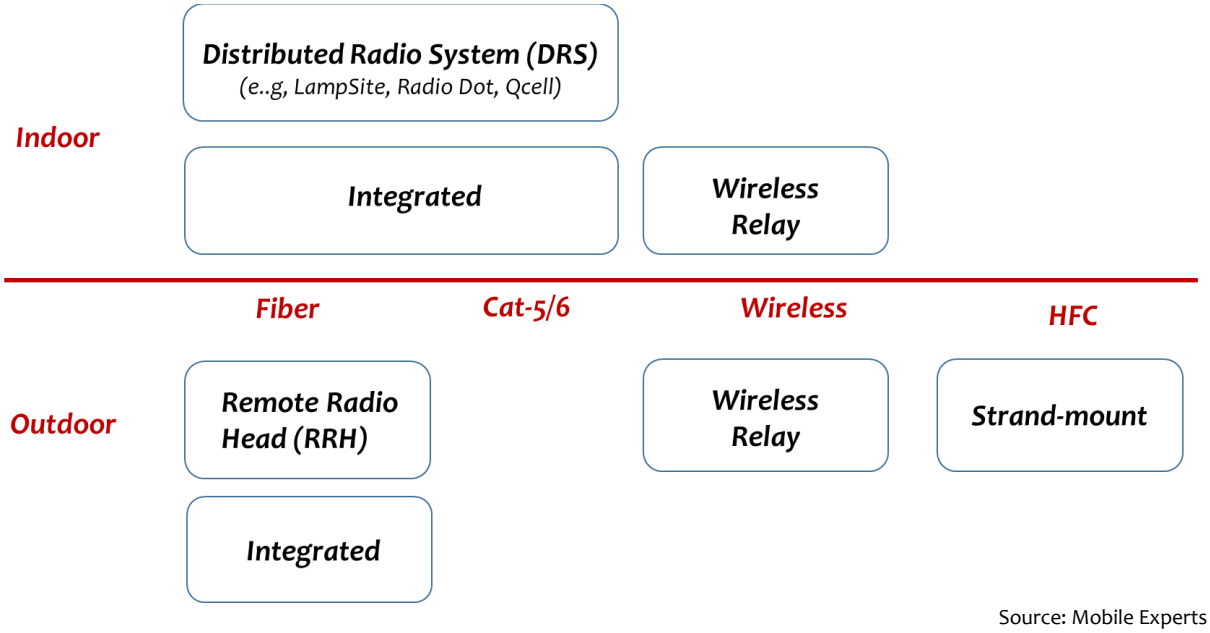
Key aspects of Residential femtocells is that it must be "plug and play" since consumers will likely be installing them at home. It must be easily installable and automatically provisioned. With small coverage requirements, Residential femtocells typically operate below 2x50mW or 100mW composite power. Moreover, simultaneous user capacity is relatively low, around 8-16 simultaneous connection handling. With VoLTE becoming more prevalent, LTE-only will become more prevalent. For some operators with limited LTE coverage, 3G/LTE dual-mode support is necessary.

Source: Samsung

Figure 13. Residential Femtocell

Small Cell Architectures and Siting Options

In this HetNet environment, "smallness" of Small Cells offer added flexibility for mobile operators to augment coverage and capacity network solution where needed. Depending on specific indoor and outdoor deployment challenges around backhaul and siting, an increasing number of small cell variants and architectures are available to overcome those challenges.



Source: Mobile Experts

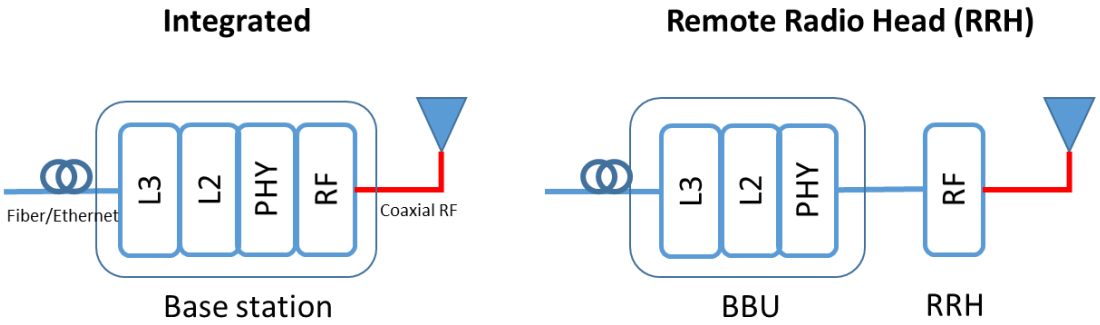
Figure 14. Small Cell Architectures by Backhaul/Siting Options

For outdoor deployments, one common Small Cell architecture is the "all-in-one" Integrated Small Cell which contains all aspects of baseband processing plus radio functions to add wireless coverage and capacity. Sometimes, Macro networks are extended through the use of Remote Radio Heads (RRH). Even though the baseband processing is handled at a "baseband pool hotel" in a data center several miles away, these RRHs provide cost-effective means to extend network coverage. More recently, Strand-mount Small Cells have come in fashion as some operators look to overcome lengthy siting approval process by cutting a deal with cable operators to leverage their hybrid-fiber-coaxial (HFC) plant between utility poles as a quick means to hang small cells on HFC strands and leverage DOCSIS or fiber for fronthaul/backhaul.

For indoor deployments, the most commonly deployed architecture is Distributed Radio System (DRS) which takes the RRH architecture "deeper" by driving multiple radio antenna units from each RRH hub unit. Another popular indoor architecture is the use of wireless relay such as Airspan's "Magic Box" which leverages LTE relay for backhaul. Integrated small cells are opportunistically used to provide hotspot coverage and capacity in smaller venues where Macro network coverage is non-existent.

Integrated "All-in-One" Small Cells

As shown below, an "Integrated" small cell is a self-contained radio node device, which includes all Layer 1-3 baseband processing plus the radio elements. It is a highly integrated radio network element. As a comparison, RRH separates out RF radio function from the baseband function to pool the baseband resource across many radios so that the resources can be optimized in a Centralized RAN architecture. The integrated small cell is sometimes refer to as "microcell" in outdoor application with RF power up to 5W per antenna, and as "picocell" in indoor application with RF power up to 200-400 mW per antenna.

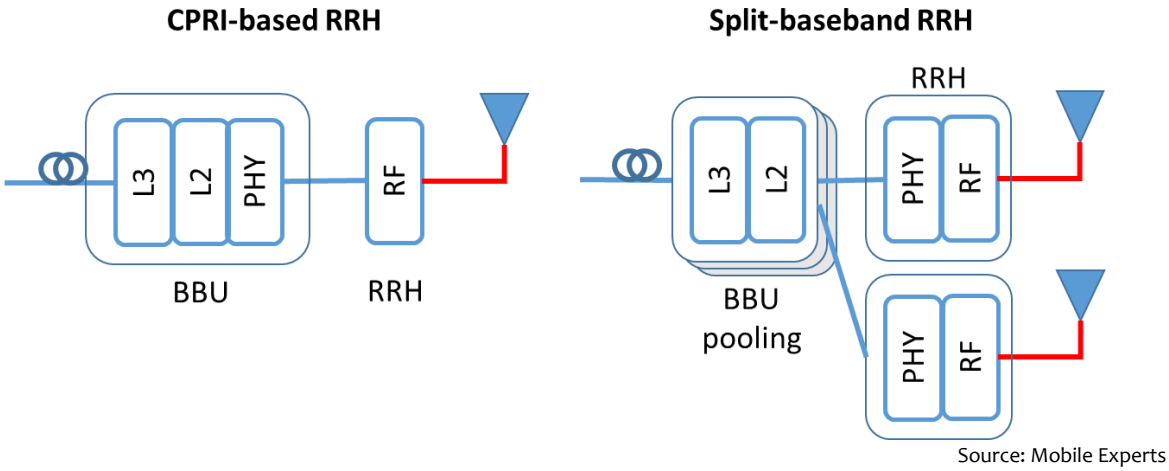


Source: Mobile Experts

Figure 15. Integrated vs. RRH Functional Overview

Low-Power Remote Radio Heads (RRH)

Macro networks can be extended, both indoors and outdoors, through the use of low power Remote Radio Heads. For the past three years, Mobile Experts has forecasted these units using the CPRI or other PHY/RF digital interface as the defining characteristic of a "Low power RRH."



Source: Mobile Experts

Figure 16. CPRI vs. Split-baseband RRH Functional Overview

Now, this category is becoming more complex, as new products are appearing with different interfaces. For simplicity in this year's forecast, we will continue to make predictions for two segments of RRH units:

1. CPRI-based RRH units (where the fronthaul takes place at the PHY/RF interface in digital baseband data); and
2. Split-baseband RRH units (where a new interface point is defined, leaving some baseband processing in the radio unit and some in the centralized baseband processor)

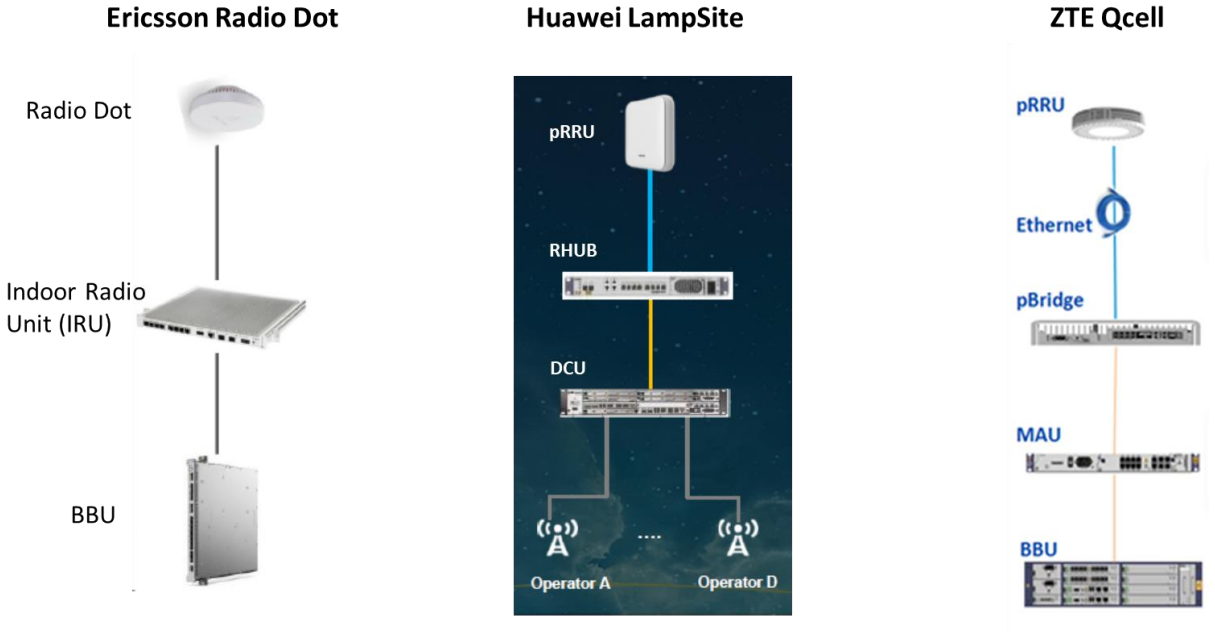
These units do not meet the strict definition of "small cells" since they do not contain all Layer 1-3 baseband processing. To be clear, we place units in the RRH category when they leave some portion of baseband processing to be done several miles away in a data center.

Distributed Radio Systems (DRS)

Distributed Radio Systems (DRS) like Huawei's LampSite, Ericsson's Radio Dot, and ZTE's Qcell take the Centralized RAN architecture concept with low power RRH radio units one step farther. Instead of the RRH feeding an antenna directly, in the DRS architecture, the RRH leads to a series of distributed RF antenna nodes to distribute RF signals "deep" within indoor venue locations. This is very similar in concept to other "distributed" systems like DAS. While the architecture and functional aspects of DRS is similar to active

DAS systems, Mobile Experts generally view DRS as a single-operator system vs. multi-operator capabilities for DAS.

The DRS systems, like Ericsson's Radio Dot, Huawei's LampSite, and ZTE's Qcell, as shown below, share the same architecture. It consists of a baseband unit (BBU), a radio head unit hub (Hub), and multiple remote radio units (RRU). A Hub is called Indoor Radio Unit (IRU) in Ericsson's Radio Dot parlance, Remote Hub (RHUB) in Huawei's LampSite, and pBridge in ZTE's Qcell. DRS allows multiple remote radio units to serve one cell with each cell individually served by each remote radio unit, which increases SINR. A Hub unit which typically drives up to eight RRUs provides power and control for RRUs and is frequency band independent. A Hub separately demodulates signals from multiple remote radio units and then combines the signals in the BBU without increasing background noise. Also, the macro parity aspect of DRS architecture allows closer coordination with macro networks to reduce operations and management costs.



Source: Ericsson, Huawei, ZTE

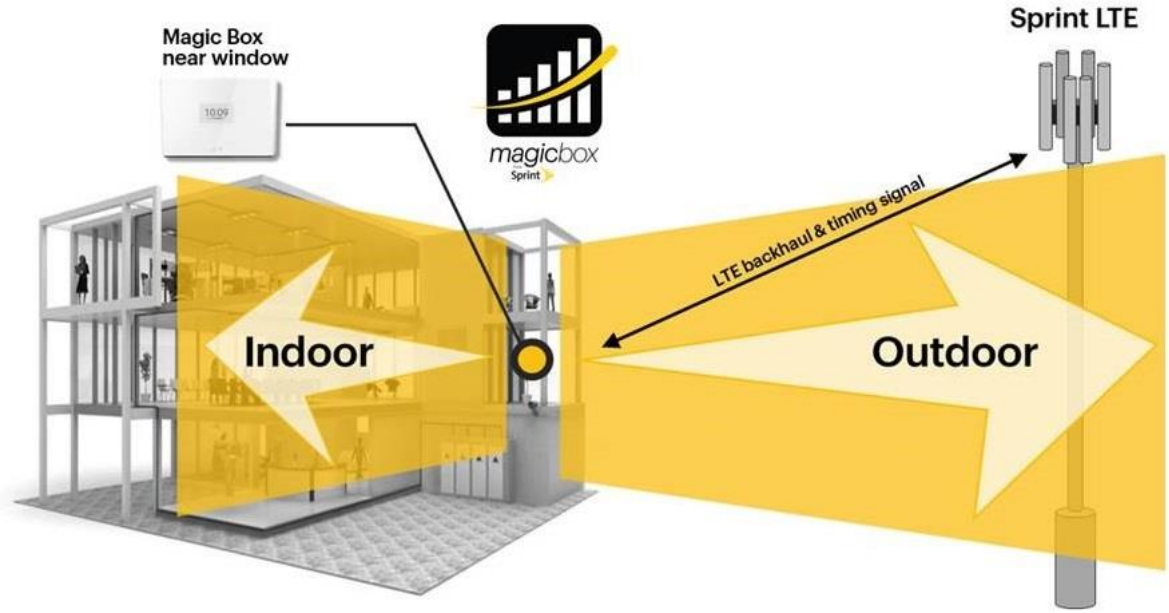
Figure 17. DRS Small Cell Architecture

In the past year, the DRS vendors introduced the "multi-operator" feature whereby multiple operators can share a DRS system already deployed in a building or venue. Essentially, the idea is for additional operators to "plug in" to existing DRS systems. To accommodate this feature, a new network element called RF-Access Unit (RAU) in Ericsson's Radio Dot architecture, Distributed Control Unit (DCU) in Huawei's LampSite architecture, and Multi-Access Unit (MAU) in ZTE's Qcell architecture, is introduced to convert external RF signal to digital CPRI. While this "multi-operator" DRS feature provides added flexibility and appeal for markets that are favorable to RAN sharing

concepts, Mobile Experts believes this would have a limited appeal in competitive markets like the USA where operators are less prone to sharing active network assets.

Wireless Relay Small Cells

In the past year, "all wireless" small cells like Sprint's Magic Box came to prominence as certain "spectrum rich" operators like Sprint looked to leverage its deep spectrum asset to overcome time-to-market and cost challenges associated with siting and backhaul. The Wireless Relay Small Cells like Airspan's *AirDensity* (i.e., "Magic Box") and Huawei's *MobileSite* indoor small cell basically integrate LTE CPE plus indoor small cell. Instead of a typical wired backhaul, the Wireless Relay Small Cell leverages LTE UE Relay feature for wireless backhaul and indoor small cell for access. On the eNodeB access side, the small cell feature resembles a typical integrated Carrier Indoor Small Cell with 2T2R and 100-200 mW transmit output power per stream. The UE Relay (CPE) provides wireless backhaul connection to Macro network using dedicated spectrum.



Source: Sprint

Figure 18. Wireless Relay Small Cell

Unlike repeaters, the Wireless Relay Small Cell essentially uses dedicated channels to regenerate signals, thus reducing noise and interference often found in traditional repeater systems. They are completely separate base stations that happen to use dedicated spectrum for wireless backhaul.

The success of Sprint's Magic Box has generated interest from other major vendors to introduce similar "UE Relay plus Indoor Small Cell" products that look to solve operator pain points around siting and backhaul challenges.

Strand-Mount Small Cells

Like the Wireless Relay small cell, the Strand-Mount small cell offers a quick time-to-market siting option for outdoor deployments. Obtaining siting approval for a wide-scale metro deployment can be long and arduous considering that the approval procedure can be different across each municipality. By working with cable operators who have a dense HFC cable footprint in the USA, obtaining small cell siting (on aerial cable strands) across multiple metro areas can be a matter of signing a commercial agreement with a few cable operators. Sprint's partnership announcement with Altice and Cox is a good market indicator of this trend. Strand-mount small cells typically support both fiber and DOCSIS backhaul options.

Source: Ercisson

Figure 19. Strand-Mount Small Cell

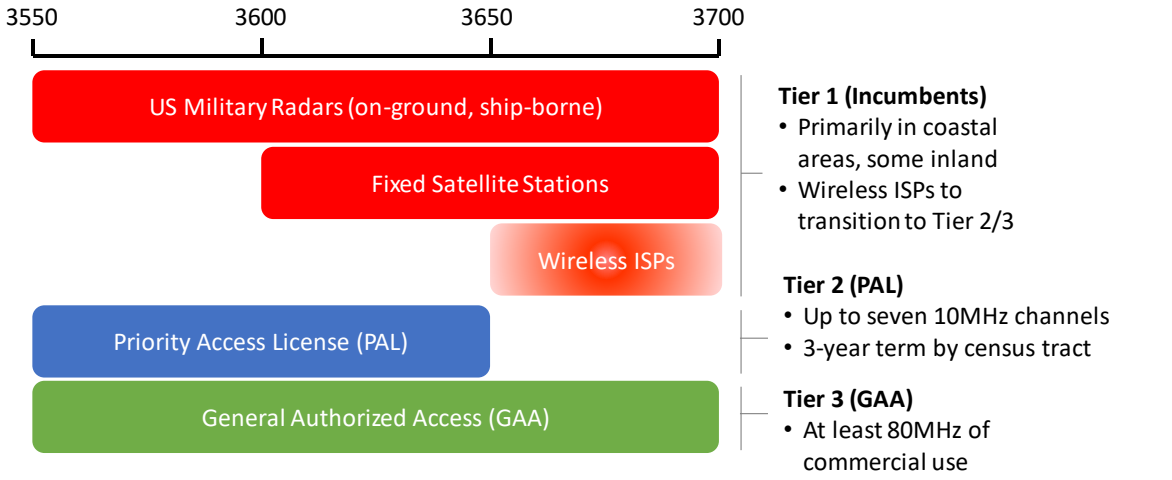
CBRS – Shared Spectrum Small Cells

The shared spectrum paradigm around the Citizen Broadband Radio Service (CBRS) in the 3.5 GHz (3550 – 3700 MHz) band has created a lot of excitement among many players in various market segments and industries, including:

- Fixed Wireless Access
- Outdoor deployment by mobile operators for capacity augmentation;
- Outdoor deployment by cable operators to reduce MVNO costs;

- Indoor deployment by enterprises and neutral hosts for general mobile broadband access;
- Private LTE for either access or IoT applications.

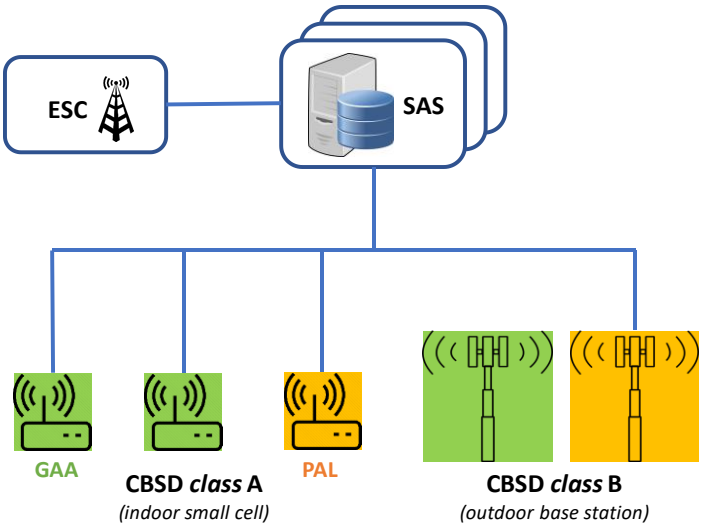
The CBRS "spectrum-sharing" paradigm relies on coordinated spectrum access among the incumbent military radars and satellite ground stations and new commercial users. The three tiers are: *Incumbent*, *Priority Access License* (PAL), and *General Authorized Access* (GAA) users as delineated below.



Source: Mobile Experts

Figure 20. CBRS Three-Tier (Shared Spectrum) Licensing Structure

A key element of the CBRS spectrum sharing architecture is the *Spectrum Access System* (SAS). A SAS maintains a database of all CBRS base stations, formally referred to as *Citizens Broadband Radio Service Devices* (CBSDs), including their tier status, geographical location, and other pertinent information to coordinate channel assignments and manage potential interferences. To mitigate possible interference to tier 1 military radar systems, environmental sensors known as the *Environmental Sensing Capability* (ESC) are deployed in strategic locations near naval stations, mostly along coastal regions, to detect incumbent activities. When incumbent use is detected, the ESC alerts the SAS, which then directs CBSDs utilizing impacted CBRS channels in that area to move over to other channels. The cloud-based SAS enforces the three-tier spectrum sharing mechanism based on FCC rules via centralized, dynamic coordination of spectrum channel assignments across all CBRS base stations in a region.



Source: Mobile Experts

Figure 21. CBRS Functional Overview

The CBRS rulemaking defines two classes of base stations: *class A* and *class B*. A class A base station can be thought of as indoor or low power outdoor small cells with a maximum conducted power of 24 dBm (per 10 MHz) and maximum EIRP of 30 dBm (1 watt). This type of small cell is similar to "enterprise-class" small cells in the marketplace with 250mW transmit power with a typical 2 dBi omni antenna or up to 6 dBi directional antenna. Meanwhile, a class B base station is meant for outdoor use with a maximum EIRP of 47 dBm (50 watts). With a very high-gain antenna, outdoor CBRS base station can potentially be used for fixed wireless purposes. While indoor and outdoor base stations can be assigned to either GAA or PAL, we expect to see more indoor GAA deployments until ESC certification and PAL auctions get finalized.

The CBRS ecosystem is progressing along, though about 9 months delayed than our original forecast, with FCC certification of SAS and ESC expected in 3Q or 4Q of 2018. While there is some uncertainty around possible CBRS rule changes around larger spectrum "parcel" size and licensing term, we expect some compromises with possibly larger geographic size in key metro markets and licensing by census tract in less populated areas with a ten-year term. While the possible rule changes may impact a longer-term prospect of CBRS market, Mobile Experts believes that near-term deployment plans will push ahead as many different business models bodes well for near-term growth. Some fixed-wireless deployments are already underway. Verizon and T-Mobile are moving aggressively, each for slightly different use cases. Cable operators are moving aggressively to upgrade their networks. And the huge industrial/enterprise market is waking up, with large VARs and system integrators putting together CBRS product plans for very wide applicability.

LAA and MulteFire – Unlicensed Small Cells

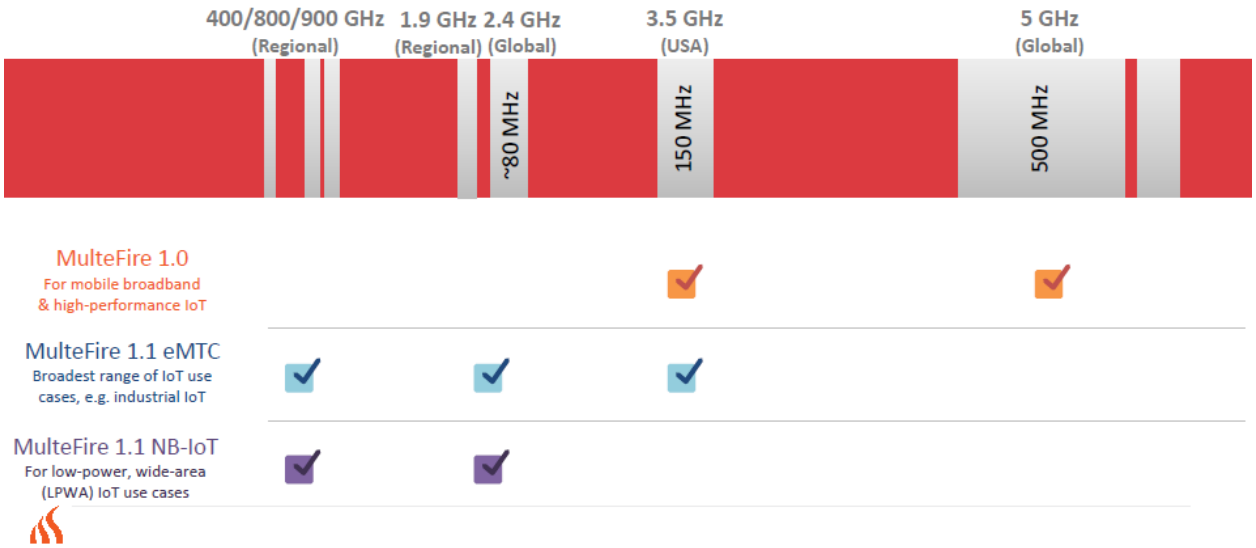
In addition to the shared spectrum use via CBRS, the use of unlicensed spectrum via LAA and MulteFire will likely add variation to the expanding Small Cell types. Leveraging LAA to tap unlicensed 5 GHz spectrum in urban/suburban outdoor settings may offer "Gigabit LTE" claim for operators and network capacity expansion in hotspot locations. Also, leveraging LAA in dense indoor environments such as stadiums could offer more efficient use of the unlicensed spectrum for wireless broadband services. However, this added benefit must be carefully weighed against the Wi-Fi experience at such venues.

In addition to LAA for capacity augmentation, some large enterprises and managed service providers are eyeing MulteFire which can be informally viewed as LAA for those operators who do not have licensed spectrum. Unlike LAA which precludes use by those who do not have licensed spectrum, MulteFire proposes to carry both control and user traffic entirely over unlicensed band in a full TDD mode. Thus, it can be leveraged by non-mobile operators such as enterprises, venue owners, and fixed-line providers. It is unclear, however, how much the efficiency gain of LAA over Wi-Fi can be maintained in the MulteFire format---especially because 802.11ax products tout 4x average user throughput improvement.[5]

How widely will MulteFire grow in key target markets among enterprises and operators remains unclear. Enterprises have a large installed base of Wi-Fi systems and client devices. Though the neutral host and multi-operator aspects of MulteFire are clear demand drivers of this technology, whether the MulteFire ecosystem can achieve competitive equipment pricing and scale of Wi-Fi remains a big unknown at this early stage.

One likely area of market adoption of MulteFire may be in 3.5GHz CBRS deployments. Traditional mobile and Wi-Fi infrastructure vendors such as Nokia, Ericsson, Cisco, and Ruckus have joined the MulteFire Alliance and working to define an industry standard around the standalone LTE technology that can be applied in the unlicensed and shared spectrum bands. While we remain skeptical of its viability in the 5GHz band, we believe the benefits of MulteFire, namely neutral host support, private LTE broadband, and fair coexistence with other technologies may be especially compelling in the "new" 3.5GHz CBRS band use. In addition, it may provide a suitable solution for industrial IoT applications that require more deterministic service quality -- guarantees of performance will be more achievable with LTE than with Wi-Fi. As outlined in MulteFire roadmap below, the ecosystem is already thinking towards the IoT applications for standalone LTE in unlicensed bands.

[5] According to Qualcomm's MulteFire presentation dated May 24, 2016, MulteFire is expected to offer ~2x capacity gain over Wi-Fi (802.11ac). IEEE 802.11ax stated goal is to improve the average user throughput by 4x.



Source: MulteFire Alliance

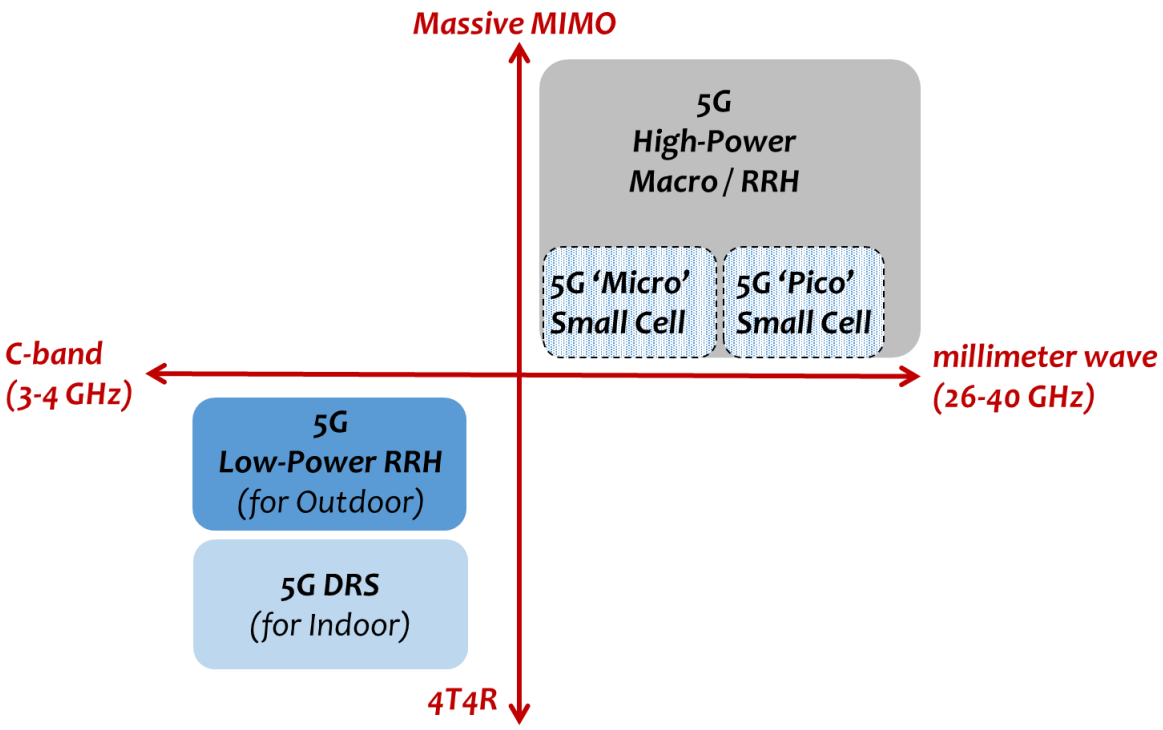
Figure 22. MulteFire Roadmap Targets Mobile Broadband and IoT

In last year's Small Cells report, we highlighted LWA and LWIP as alternative technology choices for leveraging unlicensed spectrum along with licensed small cells. Based on market activity, or lack thereof, we have concluded that there is scant demand at least among major mobile operators to leverage their existing Carrier Wi-Fi infrastructure. With 3-5 year technology transition shift, leveraging "cheaper" Wi-Fi infrastructure with licensed small cells seems like an unlikely path for the major operators to go down.

5G Small Cells

Mobile Experts expects the 5G infrastructure market to break into three major aspects:

1. Fixed broadband deployment: This will be addressed with the 5GTF and other pre-5G formats in the USA initially, but will merge with 5G NR. Based on EIRP power output, these units are treated as Macros in our definition.
2. C-band RRH: Below 6 GHz, we expect that small cells will be used in a way that is very similar to deployment of LTE at 1-2 GHz. The macro deployment will come first, but small cell deployment will follow 2-3 years later.
3. Millimeter-wave RRH units: At higher frequencies, so far we see deployment focused on fixed and early mobile applications where operators are striving for the highest possible RF power. Over the next five years, we expect some low-power mm-wave radios to emerge for indoor applications, but we have defined the outdoor RRH units above +52 dBm as a "Macro" deployment because of the operator's priority on the longest possible range.



Source: Mobile Experts

Figure 23. 5G Small Cells positioning by Band and MIMO configuration

Low-power 5G RRH units, operating below 6 GHz, will likely be employed as "small cell densification" for the 5G macro network. In some instances, Carrier Outdoor "Micro" Small Cell and Carrier Indoor "Pico" Small Cells operating in the millimeter wave bands may be employed for further small cell densification for very high-capacity links, but the control signals are going to remain on either low-band 5G or LTE. While we have seen roadmaps for such units, business cases for these units are murky at this early stage in 5G commercialization.

On the other hand, the small cell opportunity in 5G is more clear in the C-band (3-4 GHz). The use of 4T4R Low-Power RRH with 5W output power per stream provides further densification of the Macro layer. For indoor densification, all major DRS vendors, including Ericsson, Huawei, and ZTE show roadmaps with 4T4R, with 250 mW per stream output power (to account for higher C-band operation) to maintain similar coverage footprint with installed base of DRS radio nodes. We expect the bulk of 5G small cell shipments to come from 5G DRS units operating at C-band, followed by 5G low-power RRH for outdoor densification. Some 5G small cells operating at the millimeter wave bands will contribute to the near-term shipments, but we expect these to be limited in the near term.

Cellular IoT and Small Cells

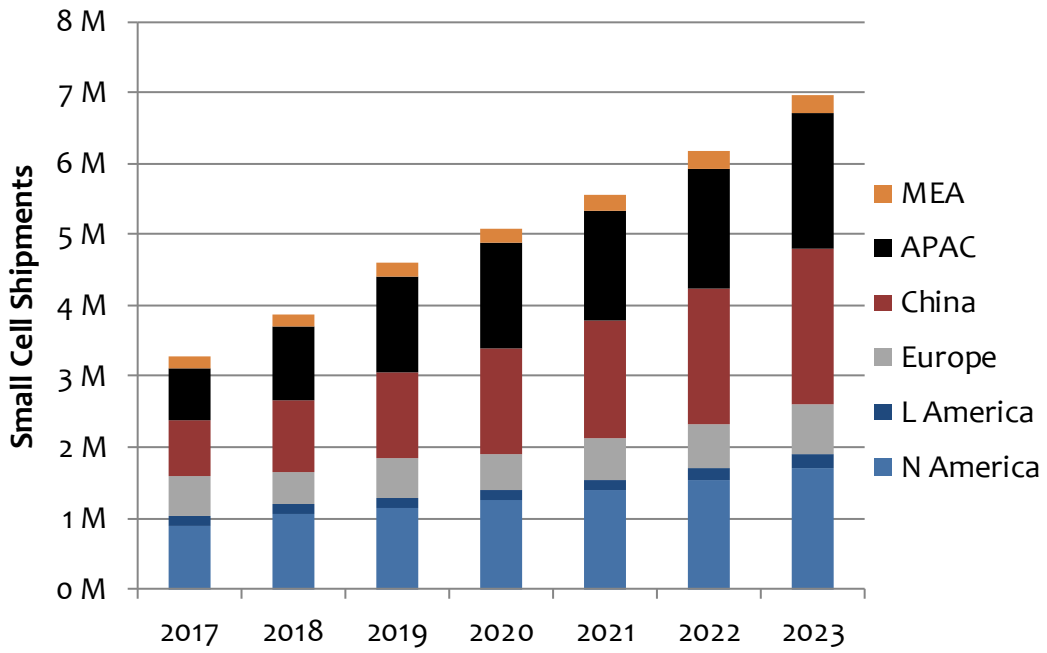
IoT applications based on Cellular IoT such as LTE-M and NB-IoT standards will drive demand for small cells in enterprise and private LTE locations. In particular, there are a few key use cases that will call for small cell deployment inside the enterprise locations, including:

- Asset tracking (such as a hospital with expensive machines on wheels)
- Fleet management (monitoring data from sensors in cars or aircraft)
- Industrial automation
- Agricultural sensors

These growing business needs will drive requirements in small cells to handle IoT traffic in addition to voice and data traffic. In particular, LTE-M and NB-IoT standards are likely to be required in some outdoor and enterprise small cells. Low-band radios will likely leverage Macro or Hi-Power Carrier Outdoor Small Cells to maximize range, certain high-band radios especially those leverage CBRS, LAA, and MulteFire may need high-performance radio front ends in the small cells to provide compatibility with IoT devices, and to maximize range.

4 REGIONAL OUTLOOK

North America, Asia-Pacific, and China regions lead the small cell market as the initial LTE network buildouts begin to lay the foundation for further densification in preparation for 5G. Reliance Jio in India has begun the next phase of densification projects incorporating both Macro and Small Cell densification efforts. Meanwhile, the Chinese operators continue their indoor digitalization with DRS deployments along with selective outdoor densification efforts. As the major operators in China, Japan, and Korea prepare for their 5G network buildouts, small cell densification projects are certain to capture a part of their CAPEX decisions. The outsized growth of these regions is reflective of large networks and huge subscriber base that those operators support. North America and Europe continue to dominate the rollout of residential femtocells and enterprise small cells.



Source: Mobile Experts

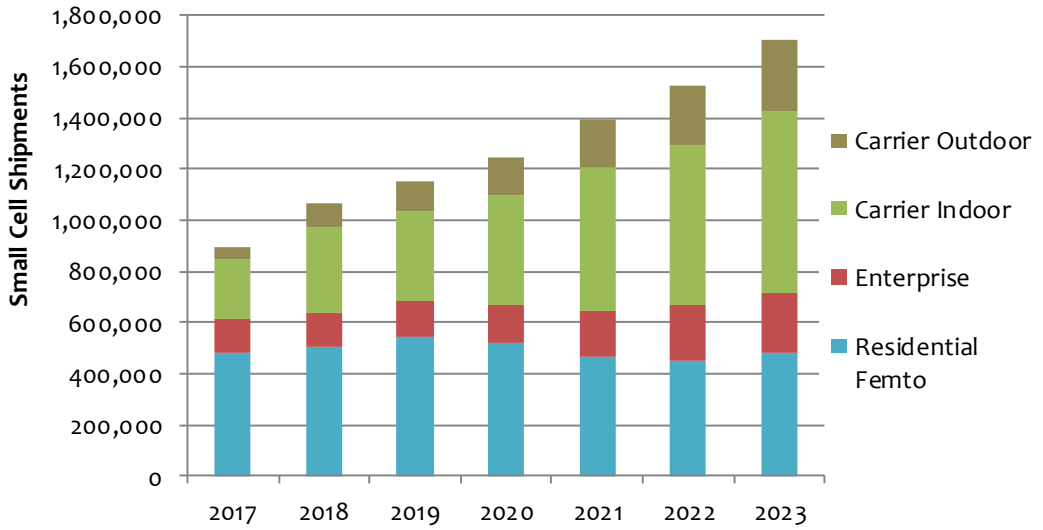
Chart 3: Small Cell Forecast, Global by Region, 2017-2023

North America

North America region, specifically the USA, continues to be an important market for small cells as American operators wield large capital budgets yearly. The competitive market forces in this highly contested and profitable market are forcing all Tier 1 operators to up their CAPEX plans from the prior years. With the possible merger no longer in the near-term horizon, the industry attention has come back to network investment. With different market positioning and assets, each operator is pursuing a slightly different path toward "5G" network investments, with implications for telecom infrastructure vendors and small cell specialists.

With the possible T-Mobile/Sprint merger now set aside, Sprint is poised to invest in all facets of its network, from Residential Femtocells, Carrier Indoor and Outdoor Small Cells, and Macros. With strategic partnerships with Altice and Cox, Sprint is looking to roll out strand-mount Carrier Outdoor small cells on the cable operators' aerial cables to overcome difficulties around timely access to siting and backhaul. With the success of Magic Box, Sprint has been able to surgically place coverage and capacity solution via these UE Relay small cells where needed. Meanwhile, T-Mobile appears focused on LAA and CBRS to add network capacity along with its residential femtocells and enterprise-targeted Carrier Indoor and Outdoor small cells. Verizon continues to expand its network capacity through a combination of spectrum carrier and small cell deployments. We expect Verizon to take advantage of LAA and CBRS bands to add network capacity as well. Although Verizon's commercial launch of 5G fixed services in the second half of 2018 will leverage "small" 5G millimeter wave radios, these units leverage high-power (greater than +52 dBm EIRP) RRH; hence these are considered "Macro" RRHs and are not counted in this forecast. AT&T remains on track to launch LAA in its "5G Evolution" markets, but we expect these to be small in volume in the near term.

In 2017, the overall small cell market in North America grew as a decline in residential femtocells was more than offset by the growth in Carrier Indoor small cells--especially the wireless UE relay small cells, i.e., Sprint Magic Box. We estimate that there are over 100K Magic Box units in the field, each capable of supporting two sectors. While the challenges of outdoor small cell siting is well documented in the press, we believe many strategic infrastructure suppliers are making inroads with municipalities. As a result, we observed a steady growth of Carrier Outdoor small cell deployments year or year, especially Hi-Power Carrier Outdoor units that provide macro-like coverage and capacity in urban core areas. The use of Hi-Power Carrier Outdoor units is likely to increase especially as the operators leverage higher bands. While 5G millimeter wave RRH and Carrier Outdoor units on vendors' roadmap strictly fall in the Macro category by our definition, we may see lower-power RRH and base station units that qualify as "Small Cells" in the future.



Source: Mobile Experts

Chart 4: Small Cell Forecast, North America, 2017-2023

In 2018, we forecast a strong, steady growth in small cell shipments in North America. Multiple factors are driving this growth:

- FCC's March 2018 order[6] streamlines small cell siting and review process;
- Operators are upping their network CAPEX spend especially Sprint, which has been constrained in CAPEX spend over the past several years;
- CBRS, and its various stakeholders and business models, will finally ramp up in the fourth quarter of 2018 with meaningful ramp up in 2019;
- Cable operators have been actively testing CBRS gears in field trials. While we remain cautious about heavy volumes from cable operators in the near term, their wireless entry, or posturing, may provide a meaningful uplift of small cell shipment in 2019.

As mentioned in last year's report, we expect Dish's announcement for IoT network rollout to have a negligible impact in our Small Cell shipment forecast. While Dish's spectrum holding remains a strategic aspect of North American telecommunication landscape, its network buildout plan around IoT services remains unknown, and its impact is largely confined to Macro network aspects.

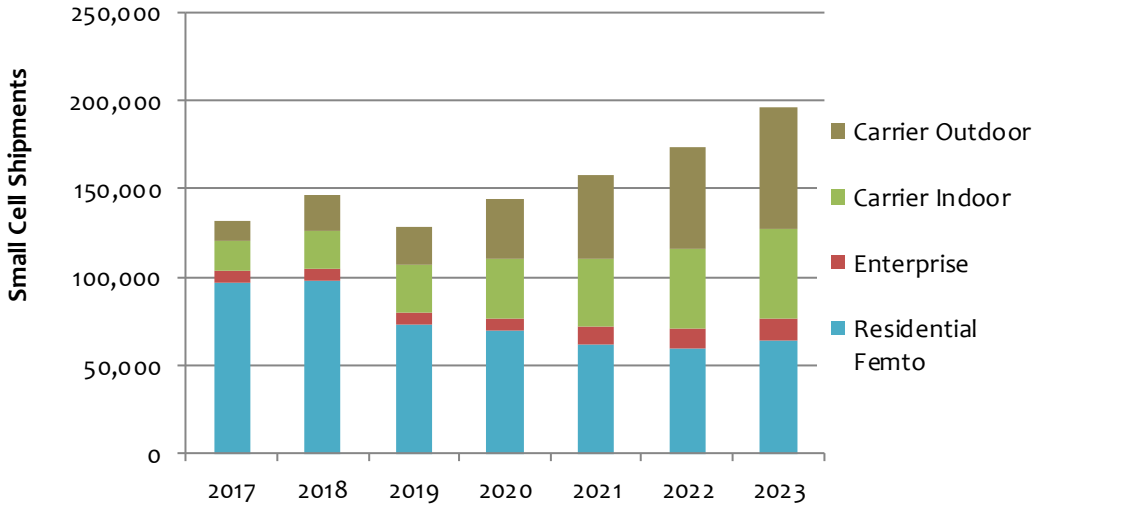
Latin America

Not much has changed in Latin America over the past year. While AT&T's entry in Mexico has provided some uplift in wireless infrastructure spending, most of that investment has been in macro LTE coverage in key population centers and major highways that connect

[6] https://transition.fcc.gov/Daily_Releases/Daily_Business/2018/db0301/DOC-349528A1.pdf

them. Investments in mobile data infrastructure continues to be made, but focused investments in small cells are expected to take some time as data and smartphone penetrations reach higher levels that warrant strategic investments in LTE small cells.

While 2G/3G picocell and microcells will continue their decline as operators increasingly target their infrastructure towards LTE, we forecast LTE small cells, especially indoor units, to be increasingly deployed by carriers to target high-value enterprise customers at key venues to satisfy the growing mobile data usage. Residential femtocells meanwhile will maintain steady annual shipments to satisfy high-end SOHO customers.



Source: Mobile Experts

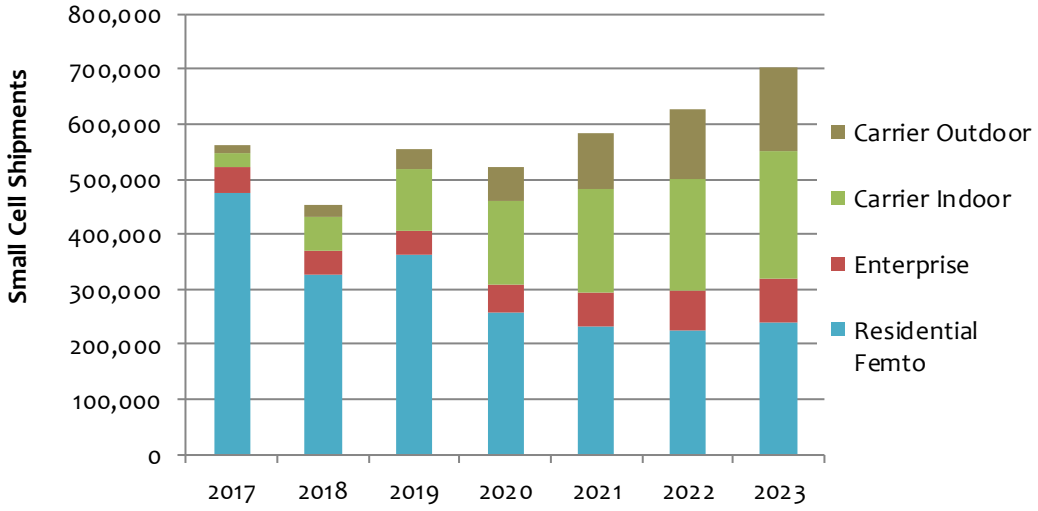
Chart 5: Small Cell Forecast, Latin America, 2017-2023

Macro economic "headwinds" in key Latin American markets like Brazil and Argentina have hampered mobile infrastructure investments as well. Those conditions have resulted in light deployment of small cells. One bright spot has been the use of Hi-Power Carrier Outdoor Small Cells that provide macro-like coverage at a lower cost than typical LTE macro base stations. Operators are increasingly looking to these "mini macro" Small Cells to provide coverage and capacity in "hot spot" locations in key urban centers.

Europe

The small cell market in Europe is heavily influenced by residential femtocells used effectively by upstart converged fixed/mobile players like Free Mobile in France and other similar players in heavily competitive markets. Due to highly competitive market conditions, somewhat influenced by a 'hands-on' regulatory regimes, the fixed mobile convergence trend has been far more prevalent in this region. With relatively low ARPU that is about 60% of the US market, both fixed and mobile operators have been looking to 'quad play' services to acquire, but more importantly to retain, subscribers.

While residential femtocells will continue to play an integral role in fixed mobile convergence markets in Europe, we expect integrated operators with mobile infrastructure to increasingly look to carrier indoor deployments of small cells such as DRS to expand mobile coverage in key enterprise venues like hi-rise office buildings and highly trafficked transportation hubs like airports. As the 5G momentum builds around other regions, major operators in Europe are starting to evaluate Carrier Outdoor and Carrier Indoor small cells for coverage and capacity solutions especially as high band 5G services in the C-band are considered for industrial IoT applications.



Source: Mobile Experts

Chart 6: Small Cell Forecast, Europe, 2017-2023

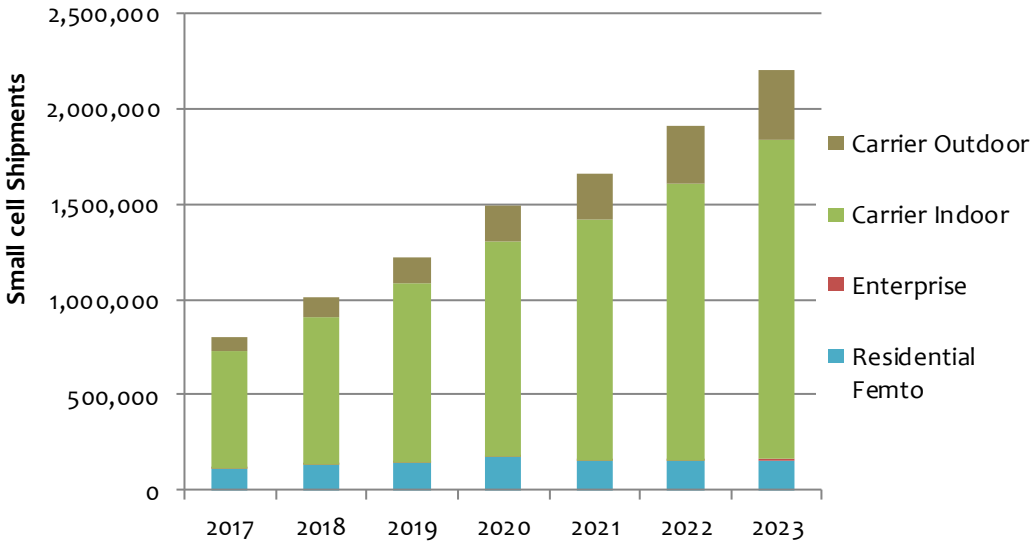
With relatively low mobile broadband ARPU, many European operators are looking to industrial applications for revenue growth. With 5G services targeting vertical industry applications that can be serviced through software-defined Core "slices," some operators view Carrier Indoor Small Cells as more relevant while High-Power RRH can provide Macro densification in outdoor applications. We forecast Carrier Indoor Small Cell shipments to outpace Carrier Outdoor Small Cells in the near term while the Carrier Outdoor Small Cell shipments to pick up pace after 2021 as the 5G small cell ecosystem matures and the cost of these network elements come down with increasing scale afforded by heavier 5G network investments in China, APAC, and North America.

China

All three mobile operators in China have largely ramped up LTE and is busy trialing 5G network trials. China Mobile alone has almost 2M eNodeB base stations in the field; hence Carrier Outdoor small cells aren't expected to make a huge dent in already "densified" network at the biggest mobile operator by base station count. While China Mobile's Nanocell initiative has largely fizzled with a follow-on tender that is about 1/10th of the 1M unit that was expected, the bulk of small cell activity in China centers around DRS indoor

deployments such as Huawei's LampSite, Ericsson Radio Dot, and ZTE Qcell. With mobile data traffic growth expected to reach 8x from 2016 to 2020 and almost 120x from 2020 to 2030 in China[7], operators continue to densify their networks especially in indoor venues where operators expect continued challenges as they operate 5G services in higher bands in the C-band and even millimeter wave bands.

China Telecom and China Unicom have been occupied with macro FDD-LTE rollouts, so they have been less focused on small cells than China Mobile. Both operators have followed China Mobile's lead in deploying DRS radio nodes in select venues. For example, both China Telecom and China Unicom have deployed Ericsson's Radio Dot product in hundreds of commercial buildings to provide robust in-building mobile service coverage. As a predominantly fixed operator, China Telecom, in particular, has been thoughtful in integrating residential femtocells and enterprise-focused small cells in its overall mobile infrastructure plan. With much smaller mobile businesses in terms of subscribers and infrastructure footprints, however, China Telecom and Unicom have struggled to compete effectively with China Mobile. They have been focused on High-Power Carrier Outdoor units to cost-effectively add coverage and capacity in urban core centers.



Source: Mobile Experts

Chart 7: Small Cell Forecast, China, 2017-2023

The enterprise small cell market is almost non-existent in China as it is customary for operators to take the lead in in-building wireless projects. The Chinese operators take primary responsibility for providing mobile coverage everywhere – both outdoors and indoors. Hence, we do not forecast any meaningful deployments of Enterprise small cells in China. Rather, we account for enterprise-targeted small cells for China market as a part

[7] China Mobile exec at MWC 2018

of Carrier Indoor small cells in our forecast. In fact, almost all of Carrier Indoor units for China are DRS radio units.

With ample fiber infrastructure footprint in China, we expect Centralized RAN architectures with low power RRH units to be widespread in the region. China Mobile has been guiding toward this CRAN architecture vision. Based on major vendors' indoor small cell roadmaps, their DRS architectures will support 5G radio nodes that operate in the C-band with higher transmit output power to account for the higher C-band operation so that 5G DRS radio units can be mix and match onto the installed base of DRS nodes already in place. Mobile Experts forecasts a significant portion of the Carrier Outdoor units in China to be low power RRH units, especially in urban deployments.

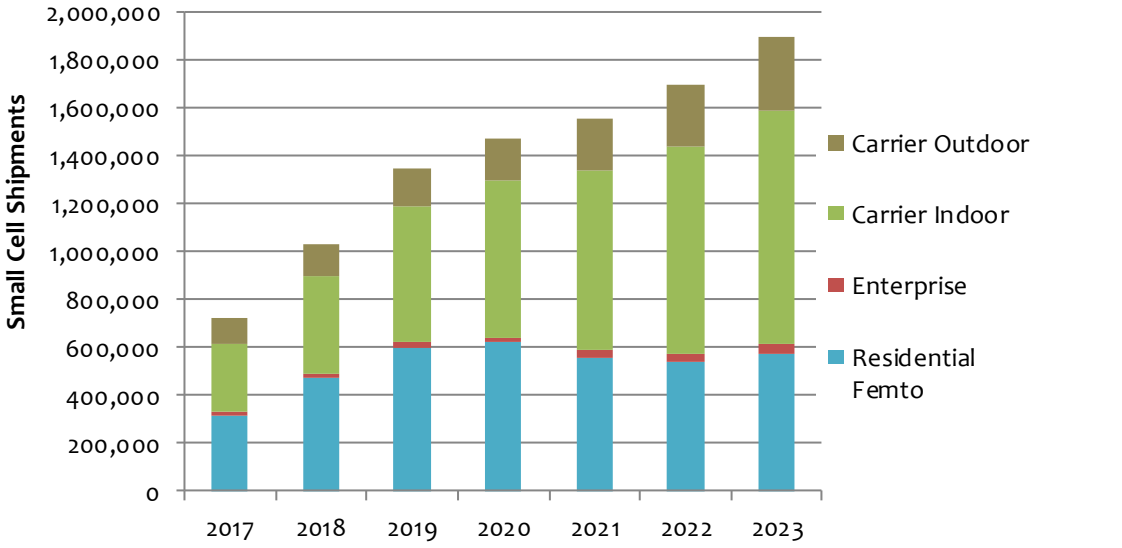
In rural deployments, we expect traditional RAN architecture to be still applicable and cover remote villages. Small numbers of traditional high-power integrated standalone units will cover remote villages, but they will dwindle over time as operators streamline towards CRAN architecture with RRH units with fixed, and sometimes wireless, fronthaul/backhaul links.

Excluding residential femtocells, China is already the single largest market for carrier-grade small cells as all three operators continue to make significant Carrier Indoor small cell investments. With robust fiber infrastructure and commercial venues that are mostly new, carrier small cell deployments for both indoor and outdoor applications seem much easier for the operators in China relative to their peers in North America and Europe who have fragmented ecosystem of regulations and infrastructure footprints.

Asia Pacific (excluding China)

While Korea and Japan have traditionally driven the small cell market in the APAC region, India has emerged as an important market for small cells with Reliance Jio's disruptive market entry. Jio's large deployments of indoor and outdoor units as a part of their coverage and capacity strategy helped to drive small cell volumes in the region. The use of LTE UE Relay for wireless backhaul to fiber-linked macro towers is another differentiating aspect of Jio's network. Unlike in developed markets where small cells are largely viewed as a capacity solution, Jio's perspective of small cell is both for coverage and capacity, and both indoor and outdoor small cells that Jio has deployed reflect this view. Small cell units deployed at Jio support relatively higher user capacity and high output power to extend coverage.

With Jio's next phase in network expansion, Mobile Experts predicts a continued growth of small cell units, especially Carrier Indoor units. For India alone, Mobile Experts predicts possible 200-400K carrier indoor units and hundreds of thousands of residential femtocells especially if Jio's competitors adopt similar network strategies using Macro/Indoor/Outdoor small cells.



Source: Mobile Experts

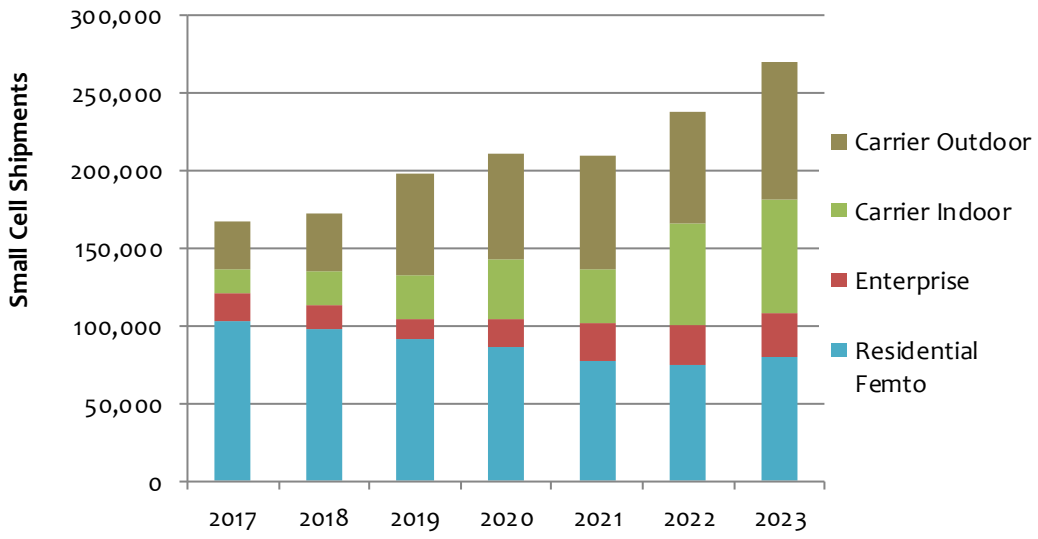
Chart 8: Small Cell Forecast, APAC, 2017-2023

Mobile Experts predicts an increasing residential femtocell market in APAC in the near term, assuming Jio's competitors take more active network investments centered around LTE small cells. In the longer term, the residential femtocell market is expected to flatten as the Jio's disruptive effect subsides in the longer term. For the APAC overall, Mobile Experts predicts that the market will shift from residential femtocells to carrier deployed indoor and outdoor small cells over time.

For the rest of APAC region, especially in Southeast Asia, CRAN-based DRS units like Huawei's LampSite and ZTE Qcell are expected to make up a large portion of carrier indoor deployments.

Middle East/Africa

The Middle East region is very diverse. It includes highly urbanized, high-ARPU markets like Dubai and UAE, as well as low-density, low-ARPU markets in Africa. For highly urbanized market like Dubai, Mobile Experts predicts that Enterprise small cells will be popular as large tall office buildings will likely be challenged with mobile coverage indoors. Carrier driven indoor deployments will drive volume growth.



Source: Mobile Experts

Chart 9: Small Cell Forecast, MEA, 2017-2023

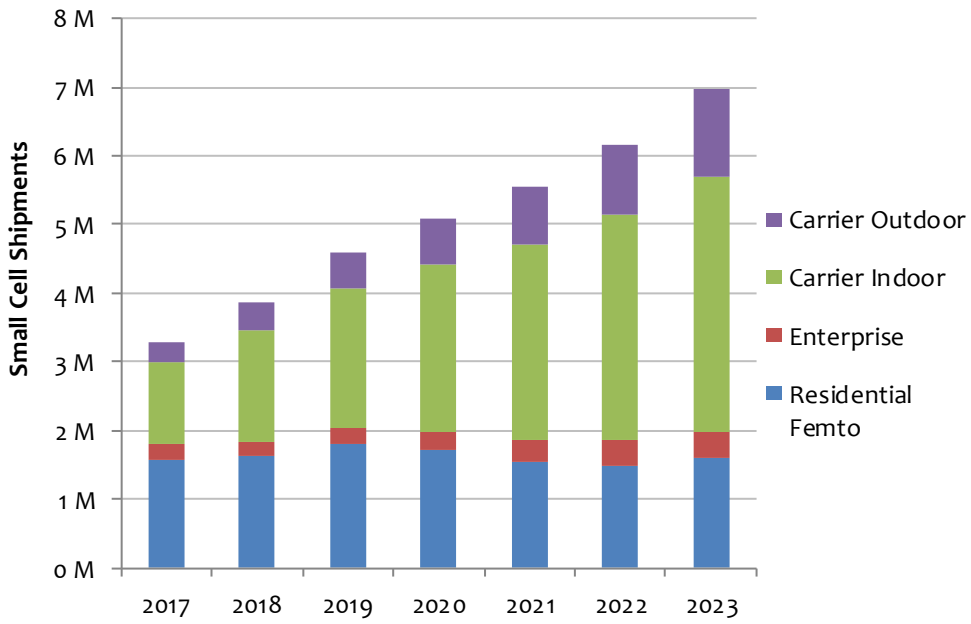
5 EQUIPMENT OUTLOOK

As predicted last year, the small cell shipment strongly grew as we saw continued network expansion indoors in China and APAC regions. With strong mobile data traffic growth and high band usage for 5G services, as two fundamental pillars of demand, we observed some innovative approaches of small cell usage last year including UE Relay small cell, CRAN-based DRS radio deployments indoors and RRH and high power outdoor small cells for continuous outdoor densification. The mobile operators will continue to expand coverage and capacity across their network footprint especially indoors. This, in turn, will drive demand for capacity increase. Increasing radio footprint closer to users will be a continuing network trend. LTE small cell deployments with shorter inter-site distances are seen as a precursor for 5G network deployment to meet the low-latency requirements as envisioned for some 5G services, and also as a battery-saving strategy on user devices. T undertaken as a first step in 5G deployment, with low latency backhaul/fronthaul and a dense grid of small cells.

Small Cell Shipment Forecast

Excluding Residential femtocells which saw a year-over-year decline, the overall small cell shipment grew 40% year over year in 2017. The Carrier Indoor small cell shipments increased almost 44% in 2017 with the Carrier Outdoor shipments growing at over 60% -- albeit from a smaller base. While the Enterprise small cells also grew, the volume shipment was significantly less than the carrier units. Most of the indoor deployments were in China, Asia-Pacific, and some in the USA. The overall small cell shipment across Residential Femtocells, Enterprise, Carrier Indoor, and Carrier Outdoor units is expected to grow at 13% CAGR from 2017 to 2023. Excluding residential femtocells, the growth rate is higher at over 20%. The annual shipment of small cells, excluding residential femtocells, is expected to double in three years to reach over 3.3M units in 2020 and triple to about 5.4M units in 2023. The Carrier Indoor and Outdoor segments are expected to see strong growth at over 20% as operators increasingly leverage small cells for "in-fill" projects especially as they ramp up to deploy in high band spectrums (i.e., 3-4 GHz C-band, 5 GHz for LAA and MulteFire, and the millimeter wave bands above 20 GHz).

The Carrier Outdoor small cell deployments via integrated base stations and RRHs on poles, cable strands, and building rooftops and facades are becoming commonplace for operators to increase network capacity and is expected to grow at high-20's. Meanwhile, the bulk of small cell volume growth is forecasted to come from Carrier Indoor deployments especially in China where indoor digitalization effort is being led by the CRAN-based DRS radio units in which operators can scale up baseband capacity and maintain "macro parity" of indoor systems with primary outdoor network.



Source: Mobile Experts

Chart 10: Small Cell Shipment Forecast, by Product Type, 2017-2023

Mobile Experts forecasts the Carrier Indoor Small Cell shipments to outpace the Carrier Outdoor shipments for a couple of reasons:

1. The majority of mobile broadband services is consumed indoors while the bulk of mobile traffic is handled by outdoor Macro and Small Cell networks; and,
2. Higher path loss for 5G services in high bands (3-4 GHz and higher) will require more indoor networks to handle more of the traffic from within the building.

The DRS small cell unit shipments in China and APAC region, in particular, will drive the bulk of the growth. The operators in those regions are more inclined to make direct network investments in indoor venues. While the Macro network densification efforts will continue, most will target 5G upgrade using the C-band at moderate 4T4R configuration given a large channel bandwidth (100 MHz possibly) will be available in China.

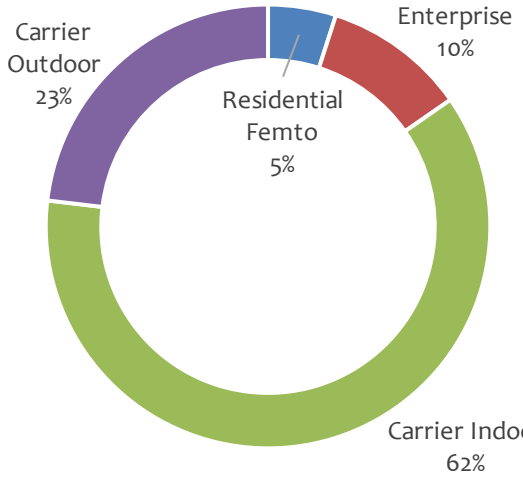
In terms of unit volume, the small cell landscape continues to shift from residential femtocells to high-performance carrier-grade small cells. While the residential femtocell represented about 80% of the total small cell market about three years ago, non-residential small cells now account for over 50% of the total annual shipments. By 2023, the carrier small cells are expected to account for over 70% of total annual shipments.

Source: Mobile Experts

Chart 11: Small Cell Shipment Share, by Product Type, 2017-2023

Small Cell Revenue Forecast

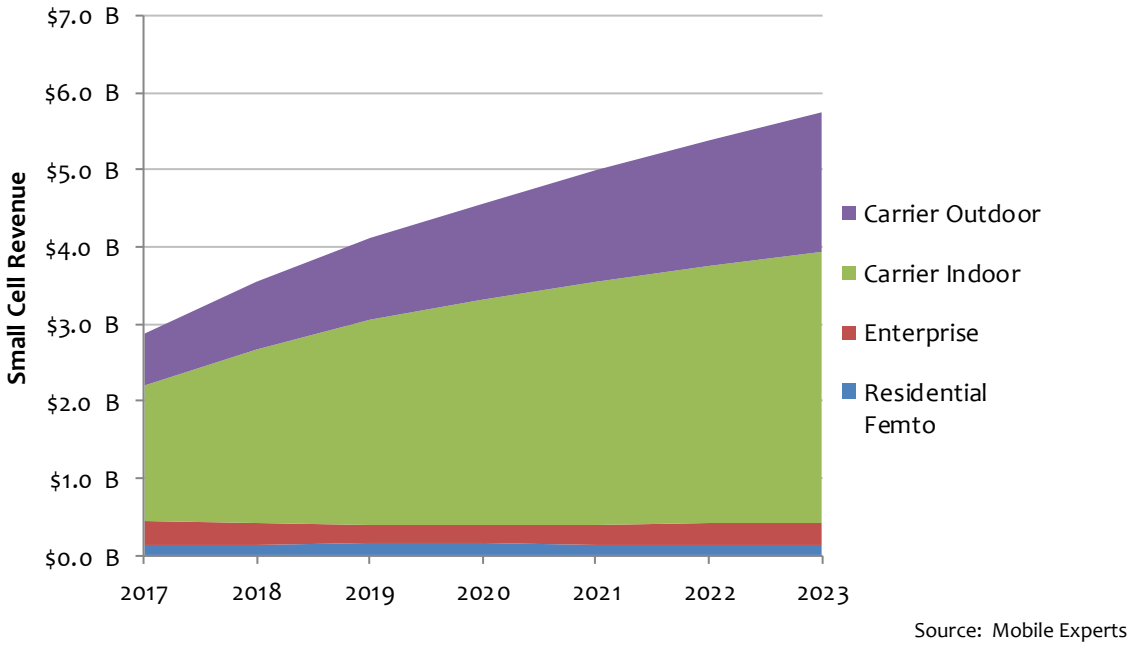
Small cell equipment revenue grew 27% year over year in 2017 to over $2.8B. The Carrier Indoor small cell segment represented just over 60% of the total, and the Carrier Outdoor segment represented about 23%. The Enterprise and Residential small cell segments constituted the remainder or about $450M in equipment sales.



Source: Mobile Experts

Chart 12: Small Cell Revenue Share, by Product Type, 2017

While the Carrier Indoor segment is forecasted to represent the largest market opportunity, rising from over $1.7B in 2017 to $$3.5B in 2023, the Carrier Outdoor segment is forecasted to grow at a higher rate at 18% CAGR from 2017 to 2023 (from a smaller base) while the Carrier Indoor segment is forecasted to grow at 12%. The overall small cell equipment market is expected to grow at low teens during our forecast period, rising to over $5.7B in 2023. The annual small cell equipment market will double during our forecast period.



Source: Mobile Experts

Chart 13: Small Cell Revenue Forecast, 2017-2023

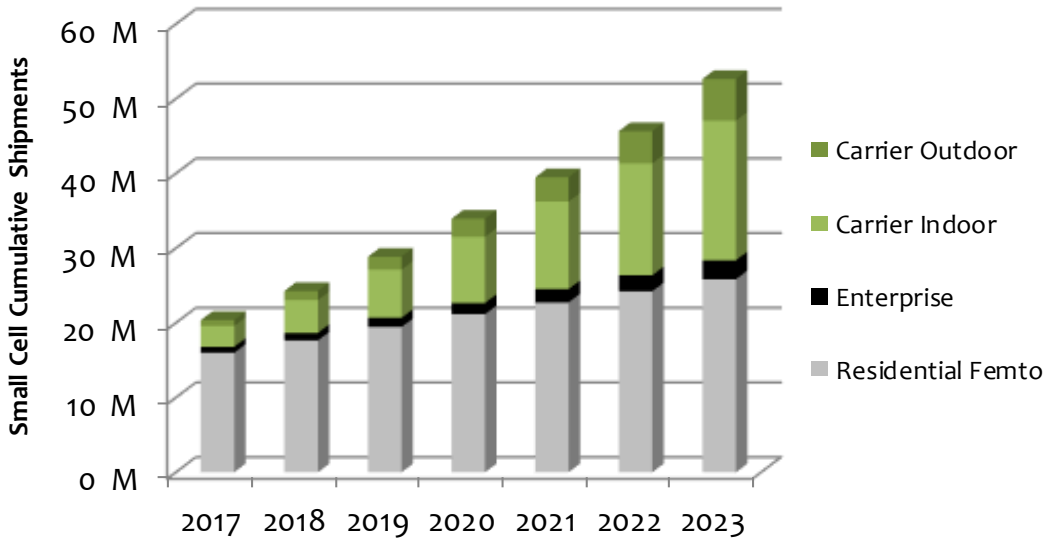
While Residential femtocells make up about half of all small cells shipped today, the revenue market opportunity is very small. With average selling price less than $100, it is very difficult for femtocell vendors to squeeze out meaningful margins to sustain on-going operations. Not surprisingly, major infrastructure vendors like Ericsson, Huawei, and Nokia mostly focus on the Carrier Outdoor and Indoor segments and sometimes outsource femtocell development to ODM partners. Meanwhile, non-Tier 1 vendors like Airspan has been able to "climb" up the food chain to claim share in Carrier Indoor segment with its Wireless Relay small cell.

In this year's report, we have made a major update to how we account for revenue contribution from DRS unit sales. Based on some market feedback, we now believe that a DRS radio unit carries a much higher average selling price than our previous methodology based on traditional RRH pricing trend. A net result is that the Carrier Indoor small cell equipment revenue, which is heavily indexed towards DRS sales, is significantly higher

than what we had forecasted last year. At the same time, over the past year, we have been forecasting downward the Carrier Outdoor unit shipments as the expected unit shipment in China had not materialized. A net result is that the equipment sales revenue from Carrier Indoor outpaces that of Carrier Outdoor.

Small Cell Installed Base Forecast

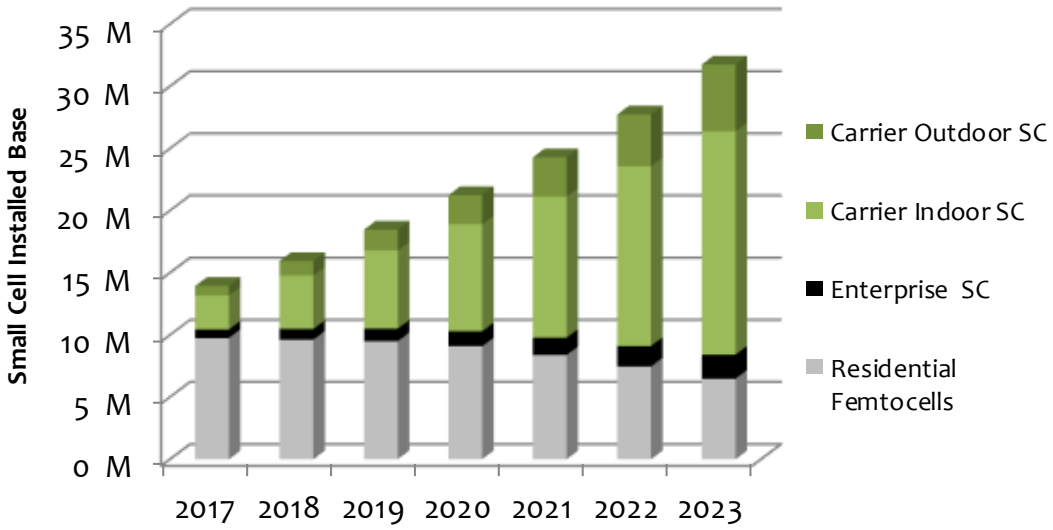
More than 20 million small cells have been shipped to date, and about 14 million units are in service. Mobile Experts tracks the shipments in terms of "Cumulative Shipments" (i.e., the total number of small cells sold to customers) and the "Installed Base" (i.e., the number of units that remain in the field). During the past year, we have been adjusting our forecast based on periodic checks with the small cell ecosystem supply chain. We had missed our forecast the pace of LTE femtocell adoption while underestimating the longevity of 2G and 3G femtocells. Our moderated view of Residential Femtocell shipments has meaningfully impacted our forecasts of cumulative small cell shipments and installed base, even though the estimated growth rates of Carrier Indoor and Outdoor remain intact.



Source: Mobile Experts

Chart 14: Small Cell Cumulative Shipments, 2017-2023

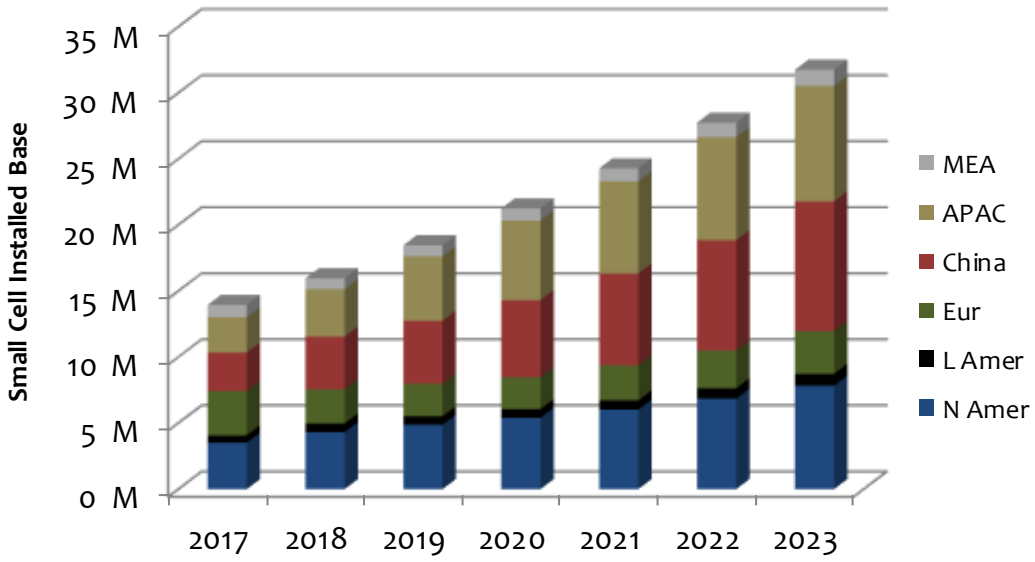
Mobile Experts projects that there is a significant percentage of residential femtocells that are turned off because the end user does not see a benefit, or simply moves to a different location where the unit is no longer needed. Hence, we estimate that the installed base of Residential Femtocells to decline over the forecast period.



Source: Mobile Experts

Chart 15: Small Cell Installed Base, 2017-2023

While North America and Europe represent regions with large installed base of small cell units, the key regions to watch are North America, China, and APAC, especially in India. In China, a large installed base of Carrier Indoor small cells, mostly DRS units, are already becoming a platform for indoor digitalization and value-added services such indoor positioning and advertising especially as the Chinese operators build out 5G services which is expected to further drive mobile traffic growth from within buildings. In the USA, the enterprise segment may truly evolve towards third-party neutral host deployment and management especially with 3.5 GHz CBRS shared spectrum services expected to come online in late 2018 and ramping in 2019.

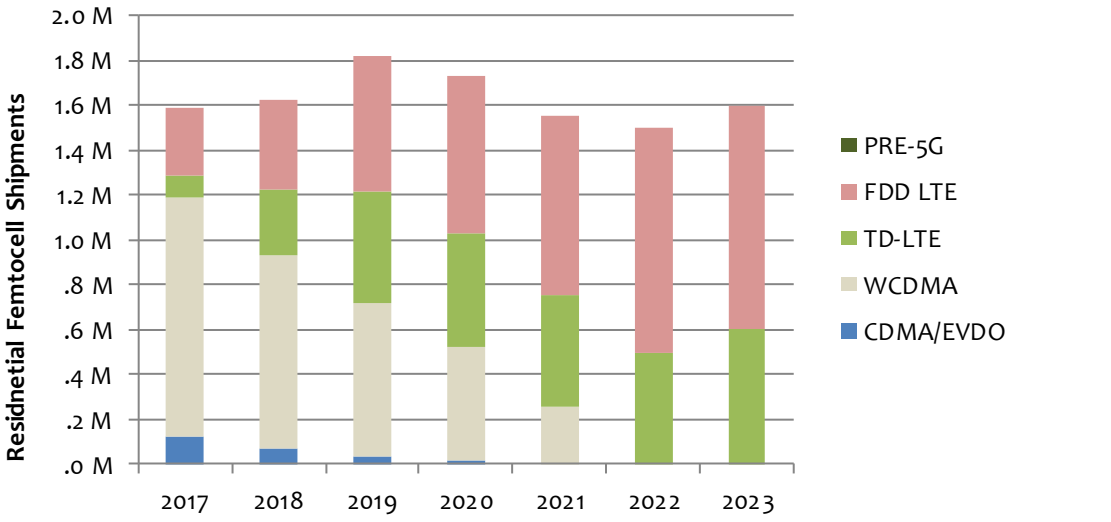


Source: Mobile Experts

Chart 16: Small Cell Installed Base, 2017-2023

Residential Femtocell Forecast

Residential femtocells reached peak a few years ago as some operators are happy to leverage fixed broadband Wi-Fi access points and voice over Wi-Fi (VoWiFi) technology as a "good enough" substitute for indoor mobile coverage solution. Instead of subsidizing femtocells, some mobile operators see VoWiFi support on iPhone and Android smartphones through fixed broadband Wi-Fi access points as adequate indoor coverage and capacity offload solution. Cost consideration is a key driver here, as mobile operators no longer need to subsidize residential femtocells to extend mobile coverage indoors. Although the growth has stalled, the residential femtocell market is expected to steadily ship around 1.6 million units annually worldwide. A key "wild card" in our current forecast is whether cable operators, more specifically those in the USA, will adopt the "inside out" strategy as a meaningful part of their mobile/MVNO strategy. If they adopt this strategy whereby residential femtocells are embedded as part of broadband gateway deployment, our forecast of Residential femtocells can significantly increase. Our current forecast does not include this scenario based on our observation of cable operators in Europe, some of whom have launched MVNO without this "inside-out" strategy with licensed small cells.

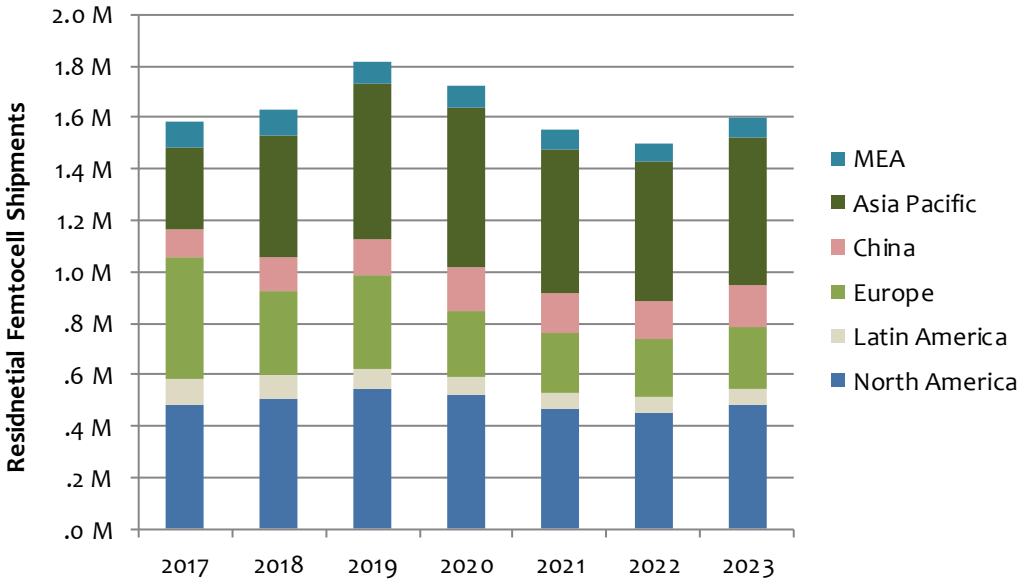


Source: Mobile Experts

Chart 17: Residential Femtocell Shipment Forecast, by Air Interface, 2017-2023

As operators continue to leverage newer air interface technologies to derive more bits per second per Hz (bps/Hz) and lower cost per bit economics, dual mode 3G/LTE femtocells will increasingly be dominated with FDD LTE units as North American and European regions which have historically dominated residential femtocell market primarily leverage FDD LTE technology. 3G and CDMA units are expected to diminish over the next few years as TD-LTE units employed in China and APAC are expected to grow in share.

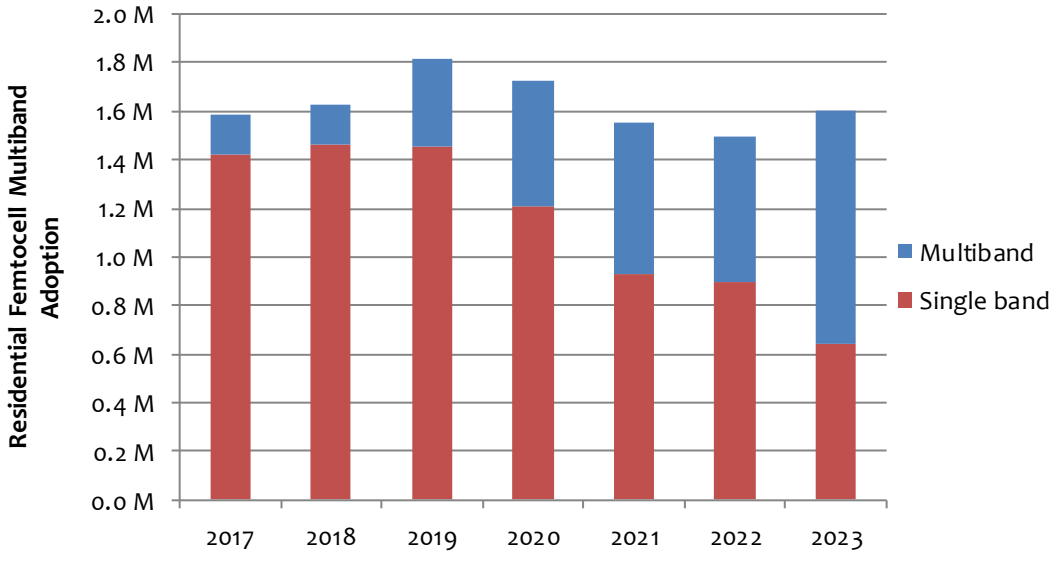
The residential femtocell market is dominated by North America and Europe, as some Tier 1 operators like T-Mobile USA are keen to deploy VoLTE as quickly as possible so that they can refarm 3G spectrum for LTE. Also, Verizon, whose licensed spectrum holding per subscriber base is relatively weaker than its peers, seems eager to seed the market with LTE femtocells to expand its mobile coverage indoors. Spectrum-constrained mobile operators especially those in the USA are expected to leverage LAA in certain indoor and outdoor scenarios to harness unlicensed spectrum to provide higher "Gigabit LTE" speed services and selectively add network capacity in hotspot locations. While we do not foresee active deployment of LAA in residential femtocells, mainly due to higher CapEx cost, the possibility is there. We do account for a minimal upside of this scenario in our residential femtocell forecast, starting in late 2018. The APAC region, especially India, is expected to drive the growth in Residential femtocells as Jio's competitors look to replicate Jio's disruptive success with further expansion of their LTE network capacity including the use of Residential femtocells.



Source: Mobile Experts

Chart 18: Residential Femtocell Shipment Forecast, by Region, 2017-2023

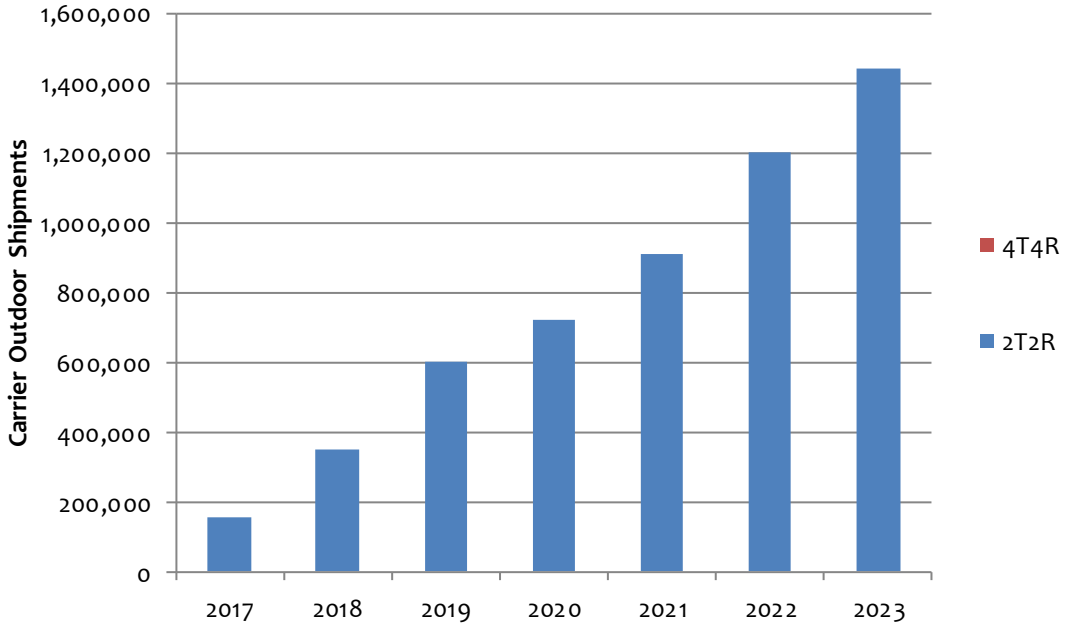
Residential femtocells are becoming more powerful with increased LTE capacity, with some SOHO-targeted units handling up to 64 users with 3G/LTE dual-band support. While the majority of residential femtocells shipped today are single-band devices, we expect an increasing number of new residential femtocells to support multiband carriers with two RF carriers for 3G + LTE configuration or two LTE carriers to possibly take advantage of carrier aggregation.



Source: Mobile Experts

Chart 19: Residential Femtocell Shipment Forecast, by Multiband Type, 2017-2023

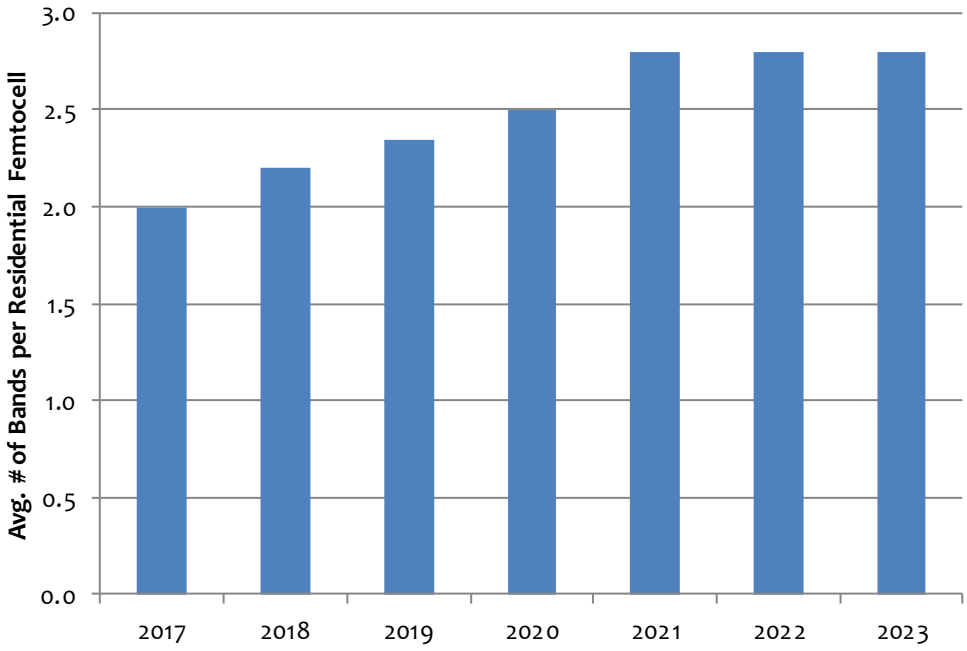
During our forecast period, we expect an increasing number of residential femtocells to support two RF carrier (2T2R) configuration with internal omni-directional antenna for easy self-install. With cost constraint, we do not expect residential femtocells to adopt higher RF carrier configurations such as 4T4R, which will be more common for higher-priced carrier-grade units for outdoor and enterprise indoor units.



Source: Mobile Experts

Chart 20: Residential Femtocell Shipment Forecast, by Antenna Configuration, 2017-2023

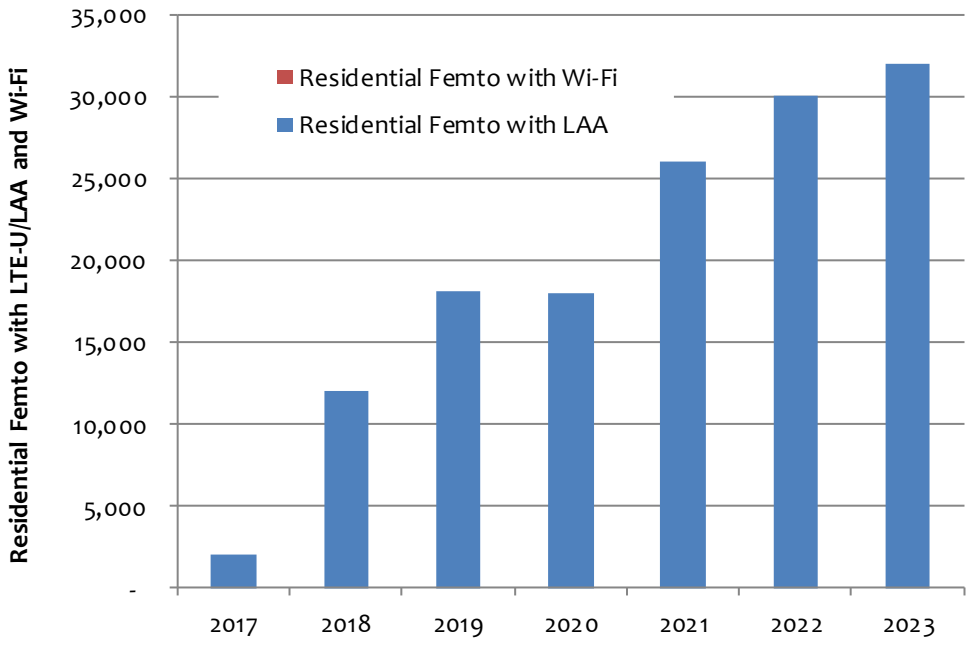
The average number of bands per residential femtocells will be around two. We expect this figure to slightly increase in the 2019 timeframe as some leading operators may look to support additional bands to take advantage of unlicensed and shared spectrum bands with carrier aggregation to support higher speeds. The weighted average of these 'high capacity' femtocells will move higher as a result.



Source: Mobile Experts

Chart 21: Avg. # of Bands per Residential Femtocell Unit, 2017-2023

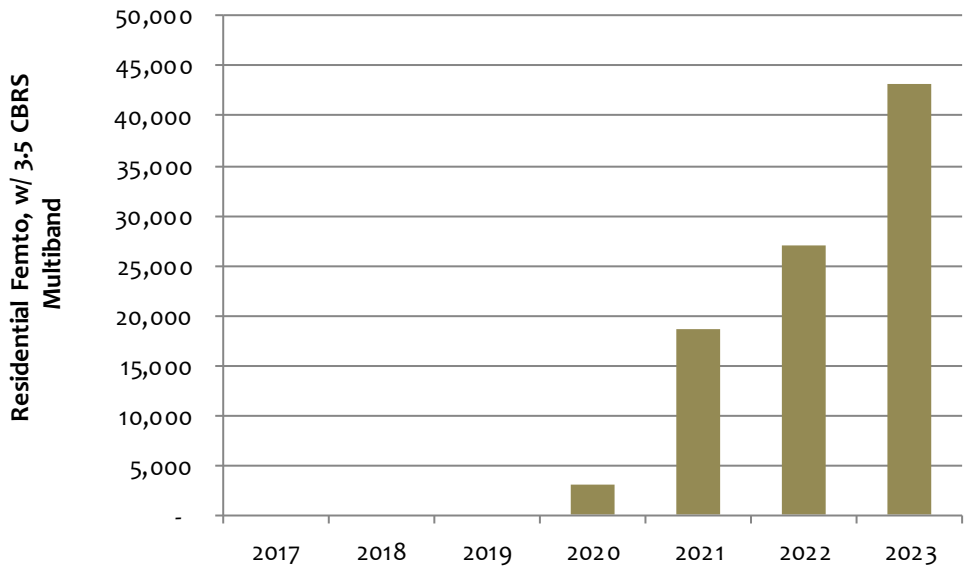
The LAA and Wi-Fi technologies offer access to the unlicensed spectrum by which mobile operators can offload mobile data traffic. With low price-point targets for residential femtocells, however, we do not expect significant adoption of these technologies on Residential femtocells. With broad availability of Wi-Fi access points in the consumer market, we expect very low adoption of Wi-Fi integrated Residential femtocells. Consumer Wi-Fi penetration is already high in most developed markets with high fixed broadband penetration; hence, integrating Wi-Fi onto residential femtocells is redundant in most cases. The LAA adoption on Residential femtocells is expected to be minimal, reaching less than 10% of global residential femtocell shipments annually. We expect most operators looking to leverage LAA will target Carrier Indoor and Outdoor small cells instead to avoid high contention areas within consumer homes to franchise venues where operators have some level of control regarding where and how unlicensed access points can be leveraged in given locations.



Source: Mobile Experts

Chart 22: Residential Femtocell Shipment Forecast, with LAA and Wi-Fi, 2017-2023

While the general adoption of 3.5 GHz CBRS shared spectrum is expected to ramp in late 2018/ early 2019, the possible Residential femtocell adoption of CBRS is still largely unknown. Mobile operators will deploy CBRS in Carrier Outdoor and Carrier Indoor units, especially in key public venues like airports, the CBRS adoption in Residential femtocells is still unknown. Cable operators are best positioned to adopt CBRS for Residential femtocells with their strong position in fixed broadband market. However, we have not observed much activity in that regard. CBRS activities thus far appear focused on traditional Carrier Outdoor and Carrier Indoor deployment scenarios. Depending on strategic intent and pace of cable operators' wireless entry and iOS and Android device ecosystem support, our forecast can potentially move up significantly, or it can go "flatline" after the initial ramp. For the Residential femtocell segment, our current prediction is the latter.



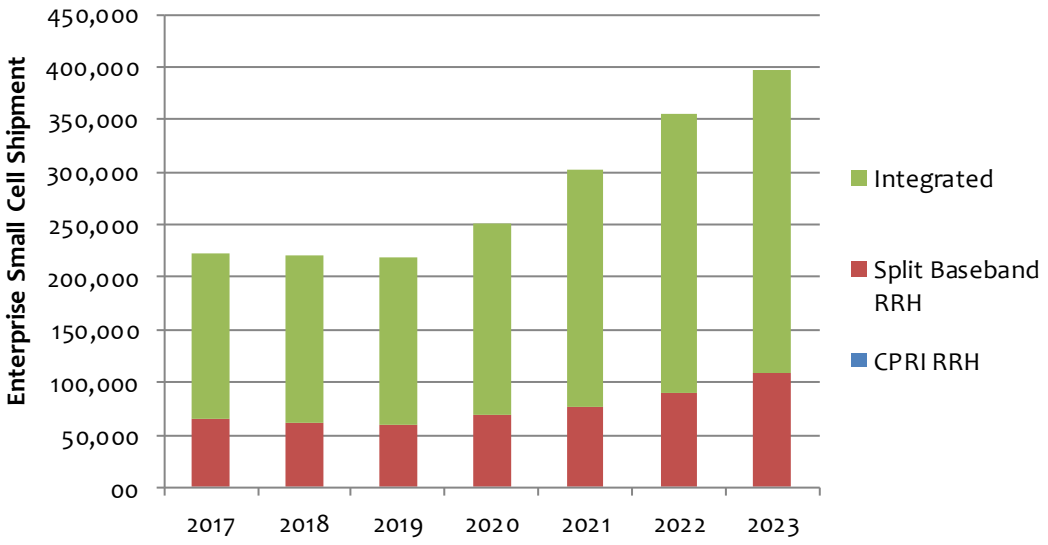
Source: Mobile Experts

Chart 23: Residential Femtocell Shipment Forecast, with 3.5 GHz CBRS, 2017-2023

Enterprise Small Cell Forecast

While the "direct-to-enterprise" model has not materialized, the Enterprise small cell market is expected to remain fairly steady for the next several years as the "go-to-market" channels get developed. While the sales ramp has not materialized as we had forecasted a couple of years back, we do see some activities as in-building wireless infrastructure suppliers, and system integrators seek to develop this market segment beyond DAS. As the CBRS market develops and the device ecosystem matures, we anticipate the Enterprise small cell market to see growth to come back in the 2021 timeframe. Pent-up demand for in-building wireless from enterprises remains strong. The recent market activities of leading DAS suppliers acquiring enterprise small cell vendors (e.g., Corning/Spidercloud and Commscope/Airvana acquisitions) provide some leading indicators of DAS suppliers looking to leverage their established go-to-market channels to sell through Enterprise small cells.

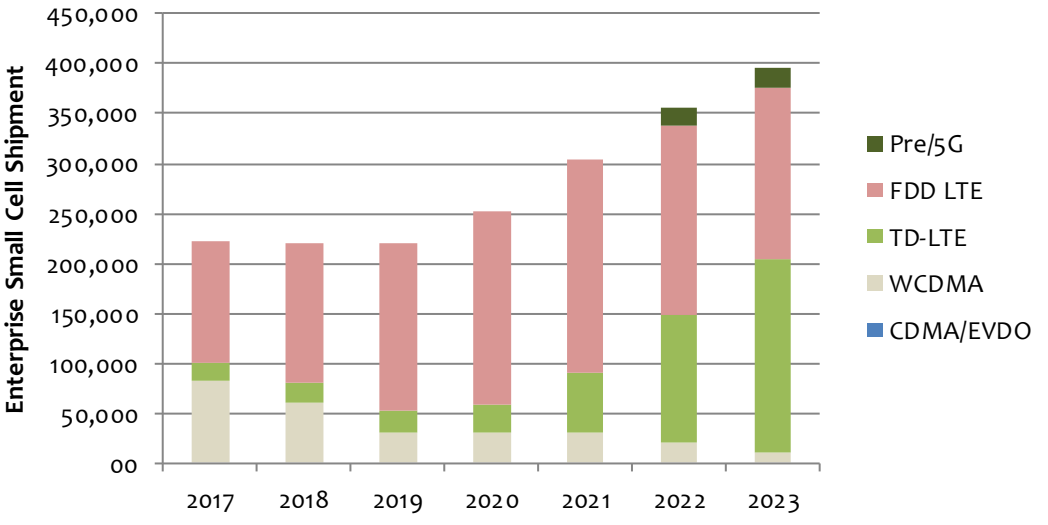
Enterprise small cells are mostly integrated units with baseband and radio functions housed in a common enclosure for quick and easy installation by IT folks. Small cells need to look and connect (via Ethernet cabling) like Wi-Fi access points which are well known to IT staff. As Enterprise small cells take on more features and higher throughput capacity, we expect fronthaul/backhaul bandwidth requirements to continue to go up. To overcome this challenge, we expect a growing number of enterprise small cells to adopt split-baseband RRH architecture where baseband and certain portions of Layer 1-3 functions are centralized while lower-layer radio functions are distributed.



Source: Mobile Experts

Chart 24: Enterprise Small Cell Shipment Forecast, by Fronthaul/Backhaul, 2017-2023

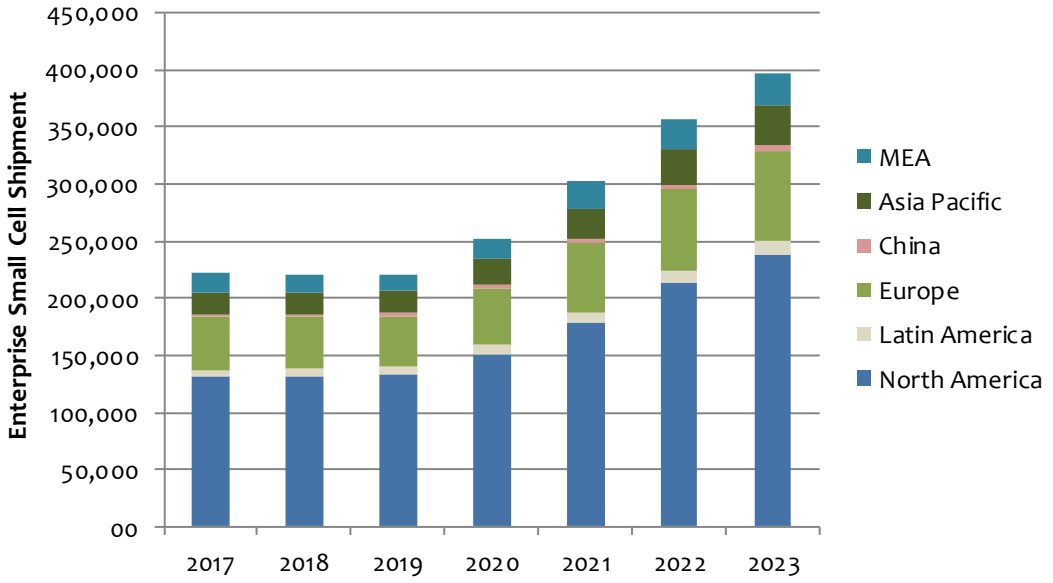
The Enterprise small cell adoption is mostly confined to North America and Europe -- due to a large number of enterprises based in those regions. Reflecting this geographic dominance, WCDMA and FDD LTE units dominate. As small cell deployments increasingly leverage TD-LTE bands in 2.5 GHz, and especially 3.5 GHz CBRS band, we expect TD-LTE to take increasing share of Enterprise small cells. We expect the majority of Enterprise small cells in the future to come from 3.5 GHz CBRS and Sprint's 2.5 GHz activities in the USA. By 2023, we forecast a small portion of enterprise small cell units to be 5G capable for private LTE applications.



Source: Mobile Experts

Chart 25: Enterprise Small Cell Shipment Forecast, by Air Interface, 2017-2023

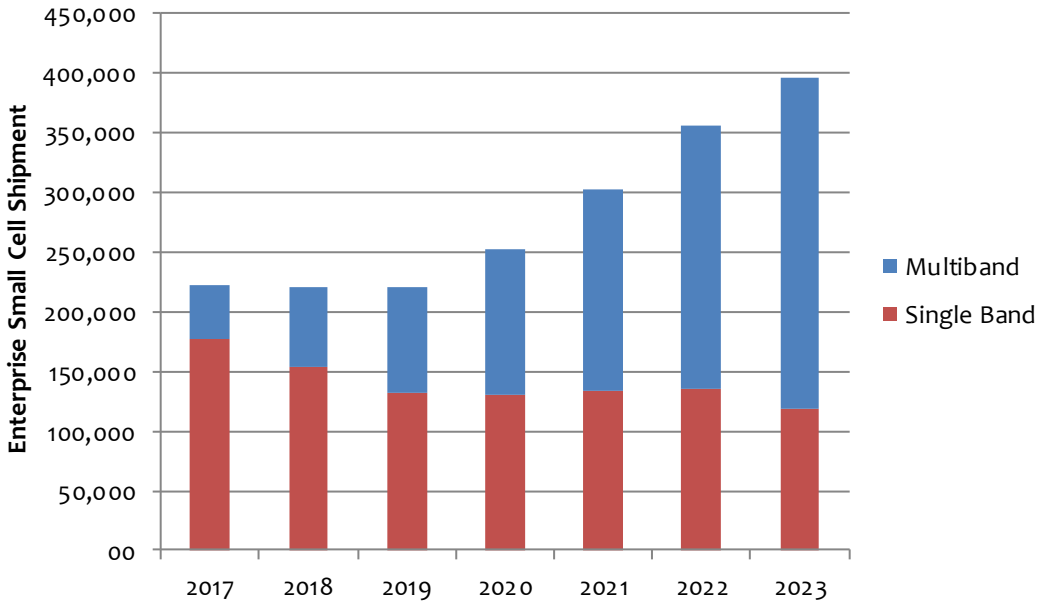
The North American and European regions will continue to lead the Enterprise small cell market segment as market and cultural norms favor enterprise-led IT/telecom infrastructure investments. While, operators in those regions will stop direct funding of in-building wireless projects beyond marquee public venues like stadiums and airports, managed wireless infrastructure suppliers like Tower companies and established DAS players will step forward to push Enterprise small cell sales. The CBRS infrastructure market opportunity in North America is expected to provide a major tailwind for Enterprise small cell growth in the general mobile broadband use case as well as private LTE applications.



Source: Mobile Experts

Chart 26: Enterprise Small Cell Shipment Forecast, by Region, 2017-2023

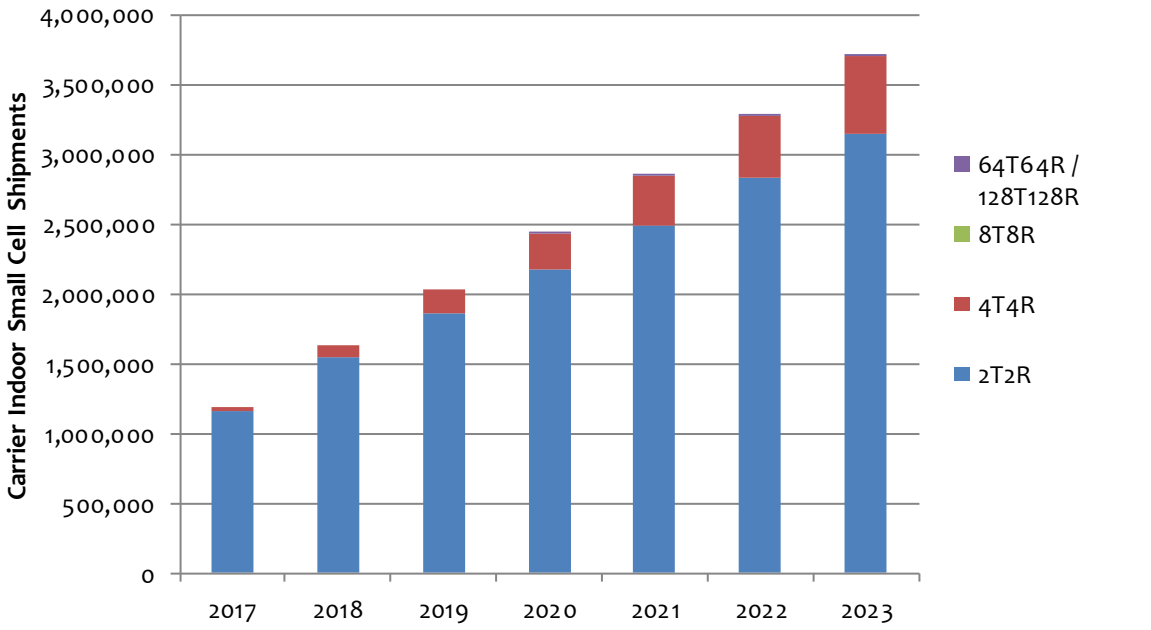
Enterprise small cells are typically higher capacity units with higher output power levels than residential femtocells to provide greater coverage and capacity. As operators deploy additional spectrum bands to increase network capacity with LAA or CBRS, Enterprise small cells will follow suit and adopt increasing number of multiband carriers and dual 3G/LTE modes. Enterprise-targeted LAA and CBRS small cells will mostly support multiple bands and be dual-carriers with 2 x 200 mW (licensed sub-3 GHz) or 2 x 400 mW (for LAA).



Source: Mobile Experts

Chart 27: Enterprise Small Cell Shipment Forecast, by Multiband Type, 2017-2023

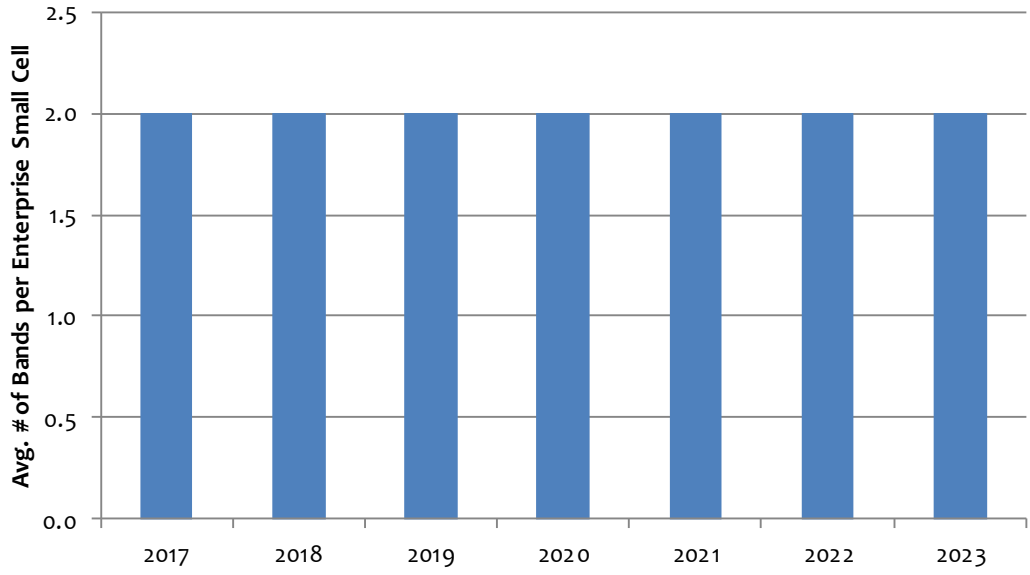
Similar to Residential femtocells, most Enterprise small cells will support two RF carrier (2T2R) configuration with internal omni-directional antenna for easy self-install. We expect some Enterprise small cell units to support 4T4R configuration to take advantage of carrier aggregation. Enterprises will need to support high peak data rates in hundreds of Mbps to keep up-to-date with Wi-Fi speeds. While we do expect 5G enterprise units operating at the millimeter wave band to support high order MIMO configuration like 64T64R or even 128T128R, we expect enterprise application to follow carrier deployments. For our forecast period, we expect most enterprise applications to operate at below 6GHz and will not require massive MIMO.



Source: Mobile Experts

Chart 28: Enterprise Small Cell Shipment Forecast, by Antenna Configuration, 2017-2023

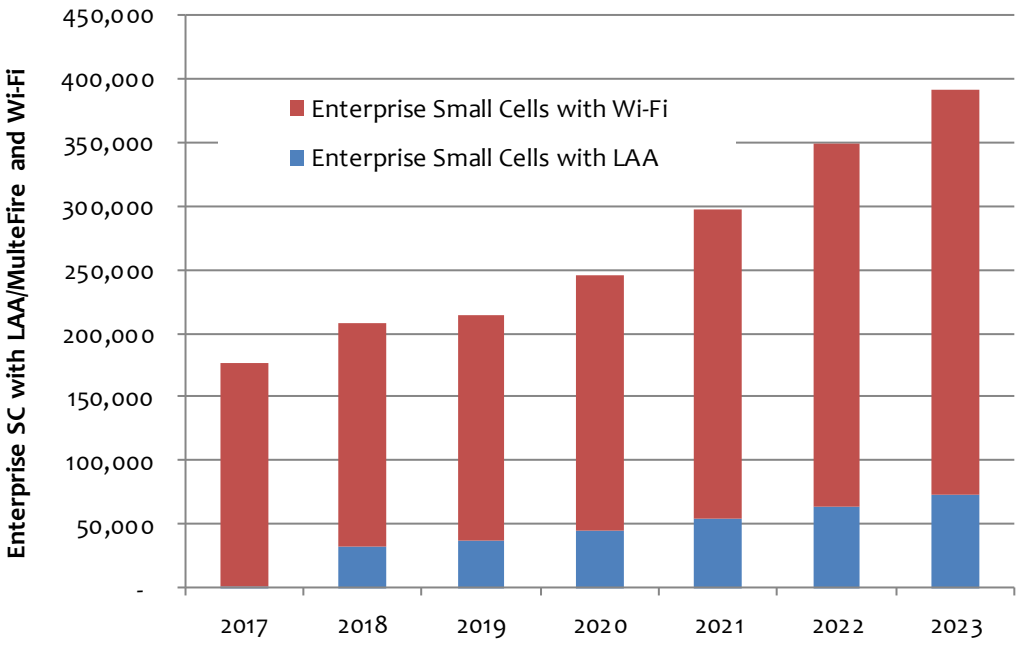
The majority of Enterprise small cells today support dual-carrier support. As operators add additional carriers to take advantage of carrier aggregation for higher capacity throughput and speeds, both integrated and RRH variants will increase additional carrier support. We expect future devices to provide three carrier band support starting in 2019.



Source: Mobile Experts

Chart 29: Avg. # of Bands per Enterprise Small Cell Unit, 2017-2023

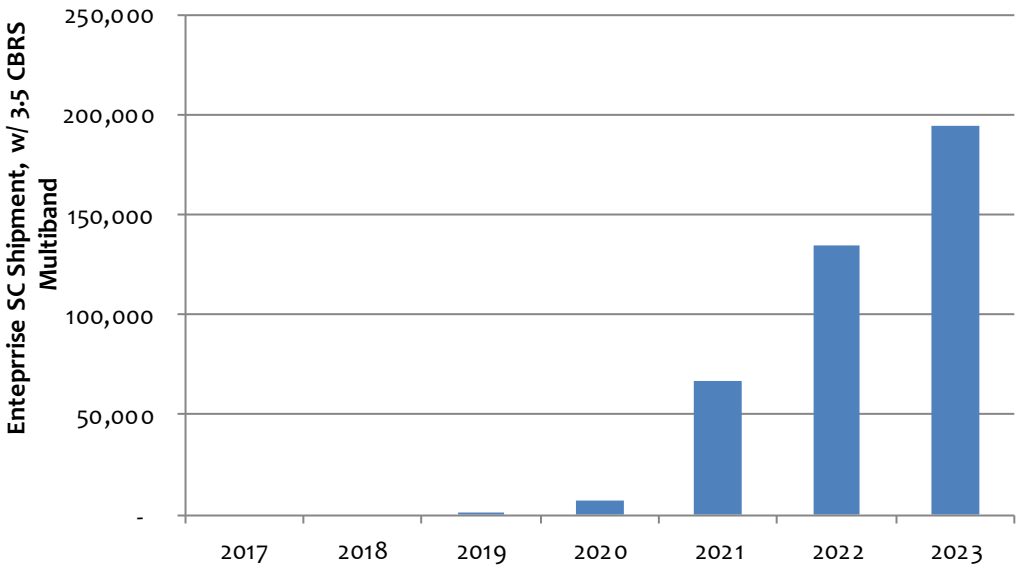
Mobile Experts anticipates more than 90% of Enterprise small cells will include Wi-Fi connectivity by 2018, especially as enterprises await the next Wi-Fi upgrade cycle to 802.11ax. During the same period, Mobile Experts believes that LAA/MulteFire adoption to be scant as enterprise value proposition of adopting LAA is not very clear. Many enterprises have Wi-Fi deployed and may be wary of deploying LTE in the unlicensed 5 GHz band due to perceived interference concerns. On the other hand, some enterprises will adopt LAA and MulteFire in certain niche Private LTE use cases like industrial IoT applications.



Source: Mobile Experts

Chart 30: Enterprise Small Cell Shipment Forecast, with LAA, MulteFire, Wi-Fi, 2017-2023

The 3.5 GHz CBRS shared spectrum technology can potentially enable neutral host small cell services that enterprises have been yearning for some time. The lightly licensed aspect of CBRS provides cost-effective means for new entrants to establish a shared infrastructure (and shared spectrum) model. Of course, this depends on operator and device ecosystem support to operate on this particular band. Android appears onboard (with Google's heavy investment in this ecosystem); however, it is yet unclear whether Apple will provide support for this band in its devices coming to market in 2018. Mobile Experts expects more than 80% of Enterprise small cells shipped in North America would be capable of supporting CBRS by 2023. Many enterprise small cell vendors, and even DAS suppliers have already announced CBRS products. As the ecosystem awaits FCC's actions, we expect commercial launches to begin in 2019 after a couple of years of testing and field trials.



Source: Mobile Experts

Chart 31: Enterprise Small Cell Shipment Forecast, with 3.5 GHz CBRS, 2017-2023

Carrier Indoor Forecast

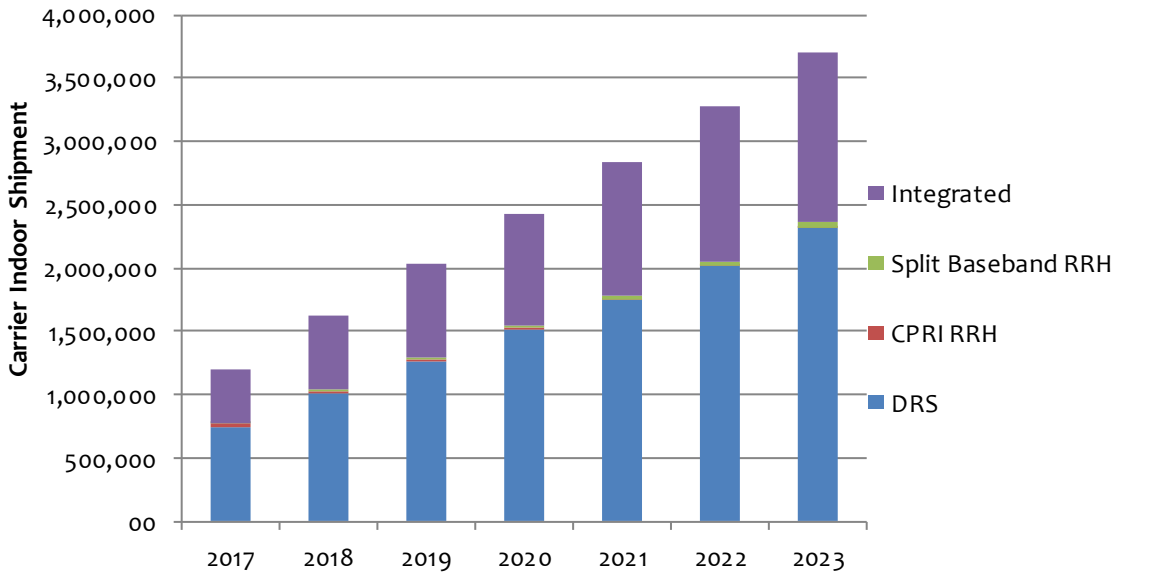
Carriers continue to deploy mobile infrastructure at key indoor venues like office buildings, transportation hubs, and retail malls. As a part of its indoor digitalization effort, China has been especially aggressive in indoor small cell deployments with CRAN architecture based DRS radios. Based on continued delay in China Mobile's Nanocell second tender, it looks like China has chosen its preference for CRAN based DRS deployment over integrated units. The Carrier Indoor unit shipment across the different DRS/RRH/Integrated categories had another strong growth in 2017, growing about 45% year over year, following a 100% growth the year before. While this strong growth momentum is sure to slow down, we see a steady growth of Carrier Indoor shipments at above 20% CAGR out to 2023 as operators continue to extend capacity indoors closer to users to meet the growing demand, and to prolong battery life on user devices.[8]

The DRS architecture--including Huawei's LampSite, Ericsson's Radio Dot, and ZTE's Qcell--has been extremely popular as the DAS-like flexibility in spectrum band deployment and centralized baseband pooling has allowed operators to optimize RF design and resource deployment for specific venue type. In 2017, DRS unit shipments reached over 700K units, making up over 60% of the overall Carrier Indoor unit shipments. Mobile Experts anticipates continued growth of this architecture for operators willing to make mobile infrastructure investments indoors.

The LTE UE Relay small cells like Airspan's AirDensity, or "Magic Box" as it's popularly known, experienced a strong growth in 2017. These Wireless Relay small cells (categorized

[8] Closer wireless links to small cells require less output power from user devices thus extending battery life.

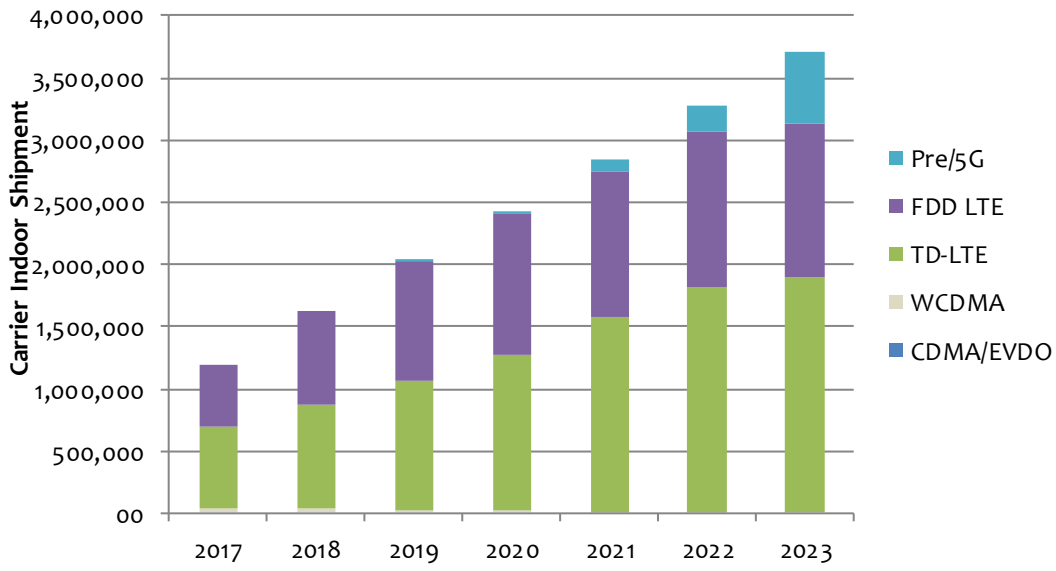
as Integrated in our forecast) were widely deployed by Jio in India and at Sprint. By combining LTE CPE and eNodeB base station functionalities, these Wireless Relay small cells offer flexible and flexible alternative to traditional small cell deployments requiring wireline backhaul, and provide cost-effective means to surgically extend coverage, and more importantly capacity, where needed. Unlike repeaters, these units contain actual baseband processing; thus, they do not merely repeat macro signal, and interfering noise, which can be problematic in traditional repeater deployments.



Source: Mobile Experts

Chart 32: Carrier Indoor Small Cell Shipment Forecast, by Fronthaul/Backhaul, 2017-2023

With strong growth of Carrier Indoor deployments in China and APAC in 2016 and 2017, TD-LTE dominates the landscape for Carrier Indoor small cells in the near term. With small cell SoC chipset implementations supporting both FDD and TDD LTE operations, incremental cost to support both operations is minimal, and we expect Carrier small cell shipments to support multimode operation.

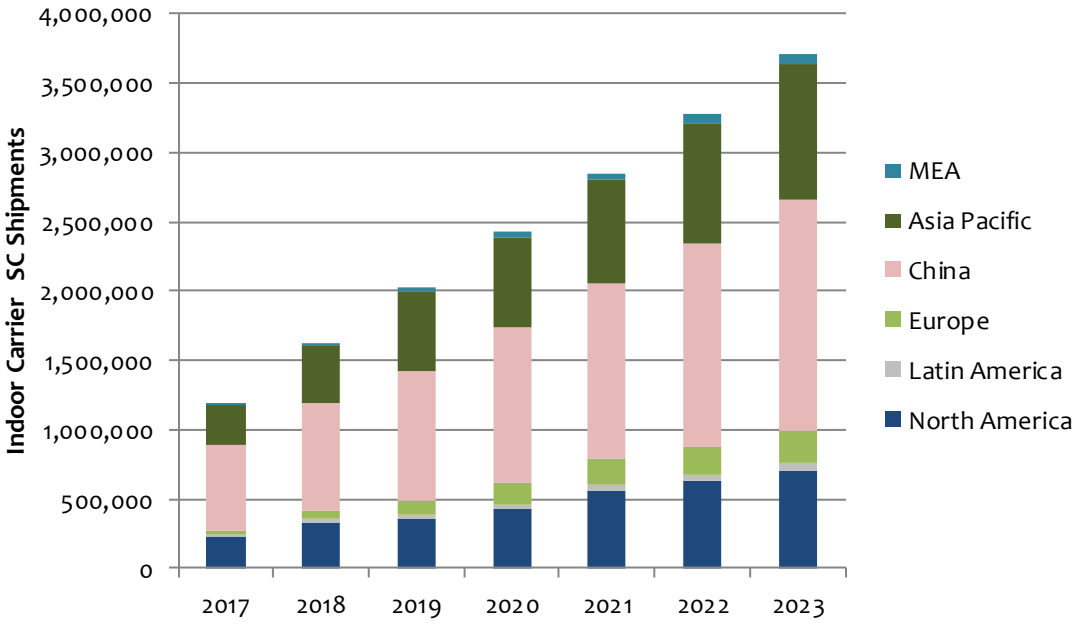


Source: Mobile Experts

Chart 33: Carrier Indoor Small Cell Shipment Forecast, by Air Interface, 2017-2023

With the preference for CRAN-based DRS for carrier indoor deployments in China, Japan, and Southeast Asia, those regions dominate Carrier Indoor small cell deployments, and this trend is expected to continue as large installed base of DRS systems provide foundation for future 5G DRS unit upgrades. The major DRS vendors including Ericsson, Huawei, and ZTE all have announced 5G DRS radios operating in the C-band to be available in the mid-2019. When the effects of DRS units are removed, the regional share of Carrier Indoor units is a bit more balanced with North America, and China and APAC combined show a similar scale of volume shipments of Integrated and RRH small cell units.

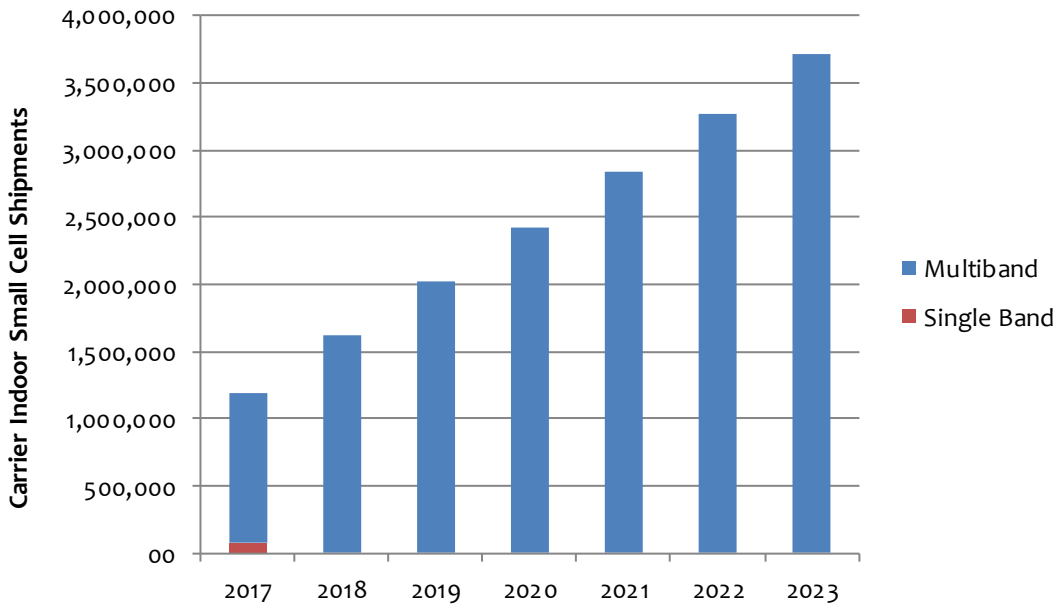
It should be noted that DRS units are similar to DAS remote units except that they are typically deployed for a single operator use versus multi-operator use case for DAS. Mobile Experts tracks a separate *Enterprise Mobile Infrastructure* market forecast that ties together market analysis of Carrier Wi-Fi, DAS, and Small Cell segments.



Source: Mobile Experts

Chart 34: Carrier Indoor Small Cell Shipment Forecast, by Region, 2017-2023

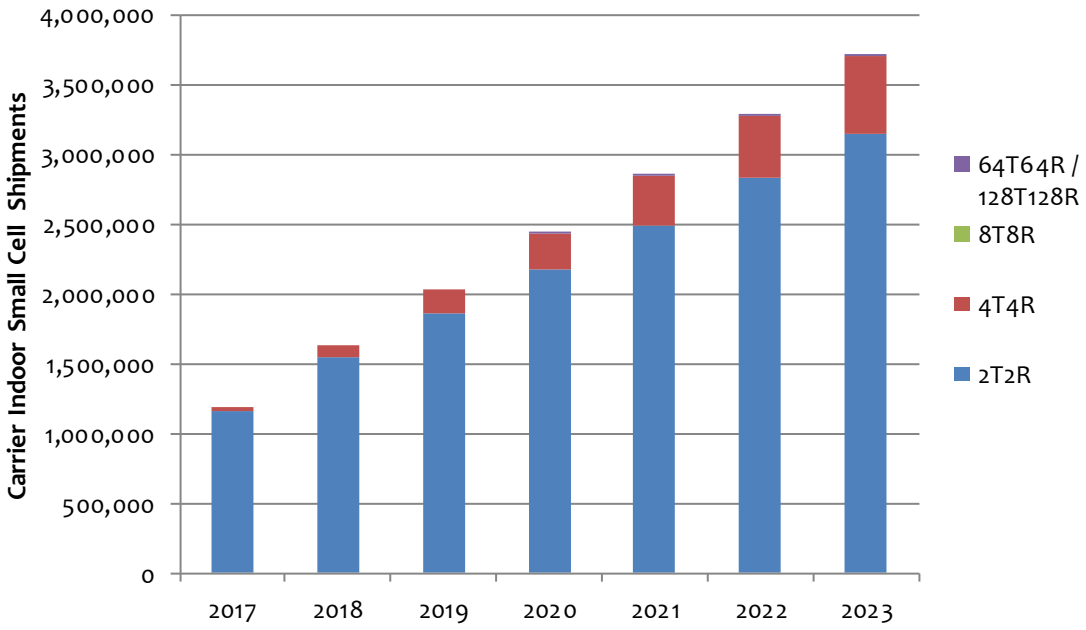
Heavy influence of DRS architecture use in the Carrier Indoor segment directly relates to wide adoption of multiband support in Carrier Indoor units. For example, Huawei's LampSite 2.0 supports three bands, and the next generation LampSite 3.0 can support up to four concurrent bands. As Huawei extends LampSite appeal to European and MEA markets with added "multi-operator" support where RAN sharing is more commonly accepted (compared to the USA where such concept is foreign), the shipment figures in Europe is expected to be influenced by a disproportionate increase in shipment figures.



Source: Mobile Experts

Chart 35: Carrier Indoor Small Cell Shipment Forecast, by Multiband Type, 2017-2023

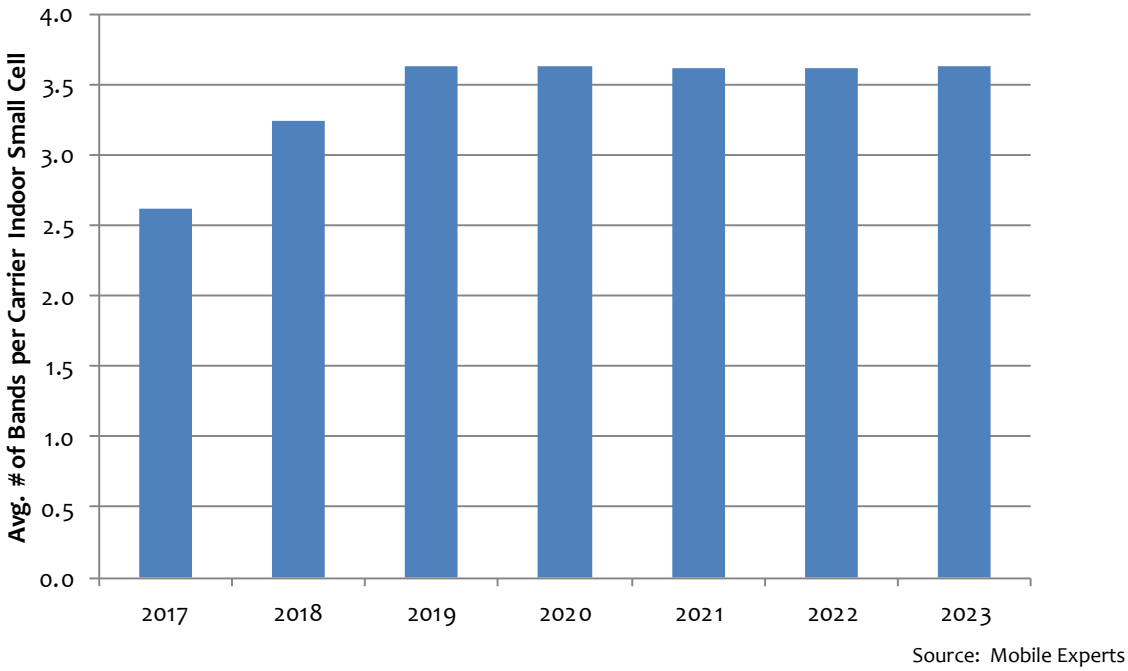
While the majority of Carrier Indoor units are expected to support internal 2T2R configuration on radio units, Mobile Experts predicts that an increasing number of indoor units will adopt 4T4R, especially in larger venue deployments. In the handset market, 4x4 MIMO is expected to become a common feature for high-end smartphones over the next few years. As operators start to trial and deploy 5G low power RRH units leveraging massive MIMO with 64T64R and possibly 128T128R configuration, Mobile Experts expects a small portion of these millimeter wave band units will be deployed in indoor settings in dense venue settings.



Source: Mobile Experts

Chart 36: Carrier Indoor Small Cell Shipment Forecast, Antenna Configuration, 2017-2023

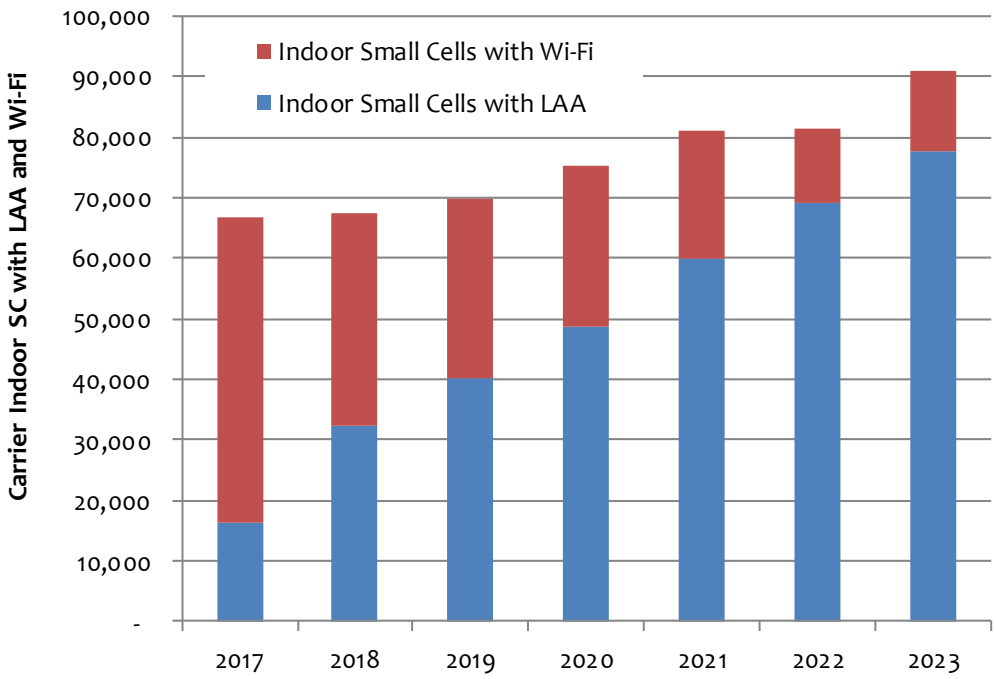
With DRS making up a significant portion of overall Carrier Indoor units, the average number of bands per Carrier Indoor small cell is heavily influenced by the number of bands supported on the leading DRS systems like Huawei's LampSite. LampSite 1.0 began with dual-band support, and the current generation, LampSite 2.0, already supports three bands. According to Huawei, LampSite 3.0 supports four concurrent bands. Overall, the average number of bands per Carrier Indoor unit is expected to increase from about 2.5 today to over 3.5 by 2023.



Source: Mobile Experts

Chart 37: Avg. # of Bands per Carrier Indoor Small Cell Unit, 2017-2023

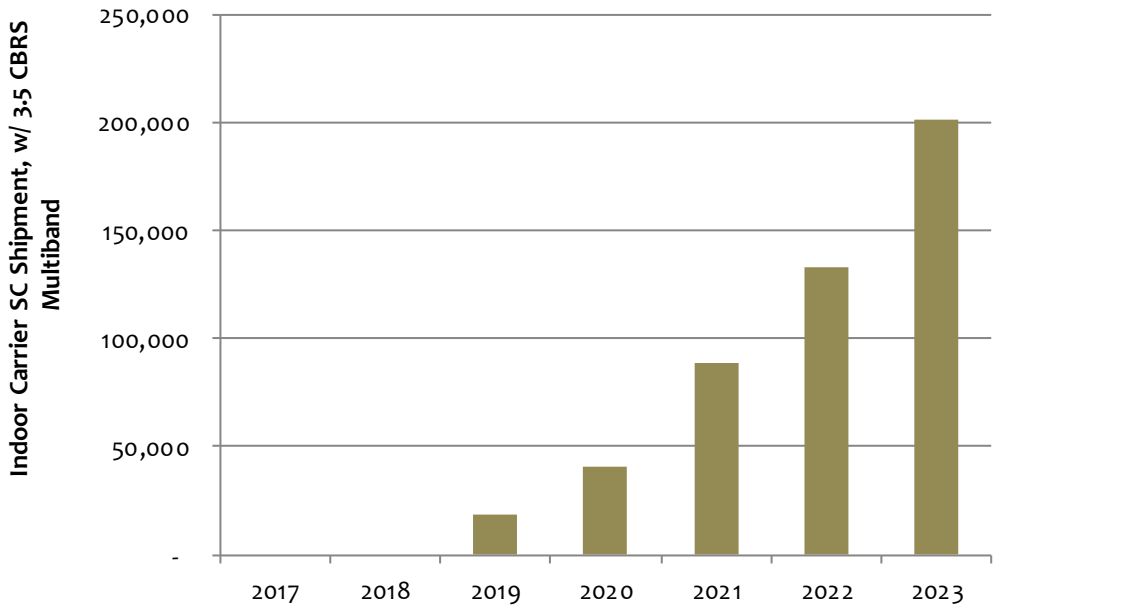
Mobile Experts predicts modest adoption of unlicensed spectrum use in Carrier Indoor context. While the number of Carrier Indoor units incorporating Wi-Fi to use the 5 GHz unlicensed spectrum band is expected to ramp down as operators look to LAA for better use of the unlicensed spectrum, Mobile Experts predicts that the LAA ramp-up to be more gradual as operators evaluate unlicensed spectrum contention issues at many of indoor locations. Overall, the combined unlicensed spectrum use through incorporation of Wi-Fi and LAA on Carrier Indoor units is expected to less than 100K units annually. This constitutes less than 3% of total annual Carrier Indoor shipments at the end of our forecast period. The use of the 5 GHz unlicensed spectrum via integrated Wi-Fi module or more directly via LAA will be limited and opportunistic in the longer term (for example, in a stadium for faster speed upgrade) as Wi-Fi will remain cost-effective and "neutral" indoor solution for many enterprise locations.



Source: Mobile Experts

Chart 38: Carrier Indoor Small Cell Shipment Forecast, with LAA and Wi-Fi, 2017-2023

While the major US mobile operators' interests in CBRS remain robust in general, indoor deployments from the mobile operators will remain fairly small. While Mobile Experts is bullish on the overall CBRS use by enterprises and neutral host providers, there are many business model challenges that have not been addressed yet. Multi-operator core networking and coexistent use by multiple operators, etc. are some of the challenges that remain with the neutral host business model. Hence, the direct mobile operator deployment of CBRS multiband small cells has been greatly reduced from our forecast last year. Enterprises and neutral host providers will lead CBRS indoor deployments later in 2020/2021 timeframe after enough user devices supporting CBRS gets "seeded" in the marketplace.

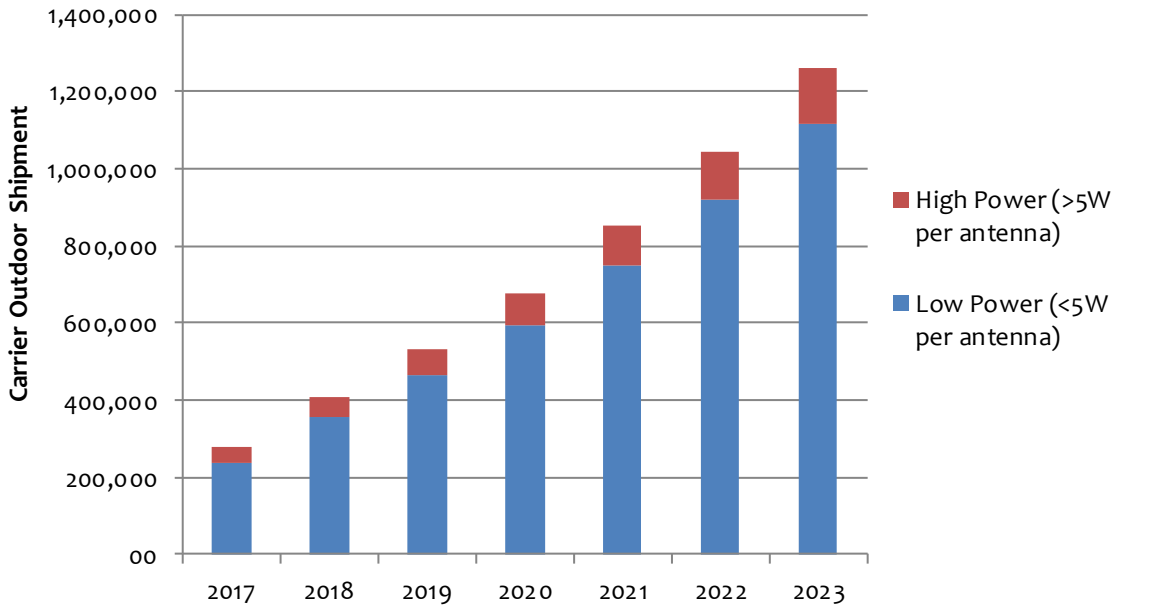


Source: Mobile Experts

Chart 39: Carrier Indoor Small Cell Forecast, with 3.5 GHz CBRS Multiband, 2016-2022

Carrier Outdoor Forecast

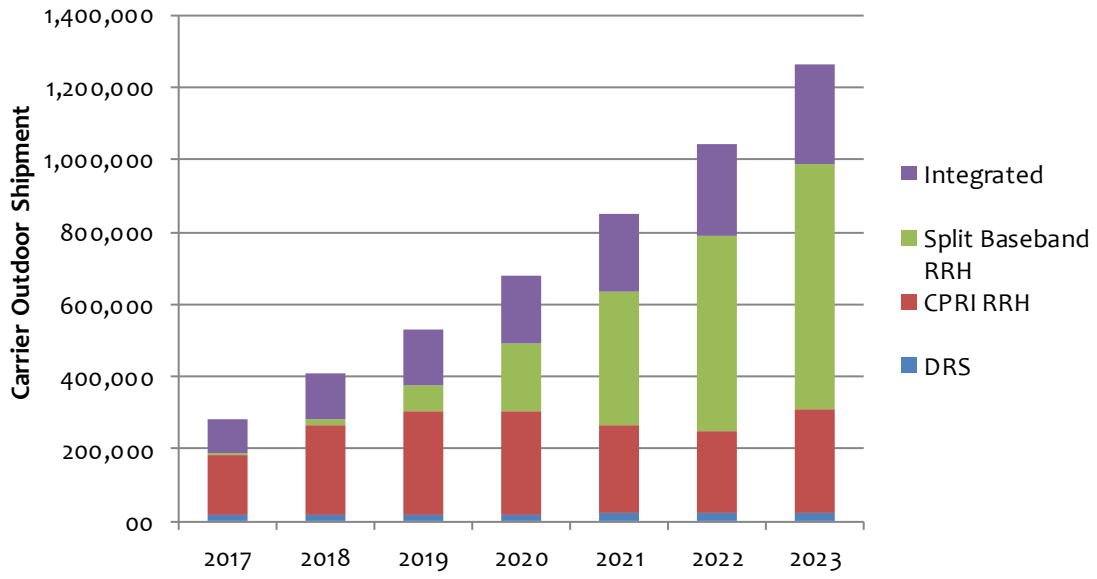
The Carrier Outdoor segment grew over 60% in 2017 year over year, largely from activities at Reliance Jio, China and APAC operators, and Sprint. This year, we are seeing growing outdoor activities at Sprint in addition to the existing outdoor deployments in China and India. Operators with limited coverage and capacity footprints in dense urban and in rural areas are increasingly leveraging Hi-Power Carrier Outdoor units to provide cost-effective mobile coverage and capacity solution. By deploying Hi-Power Carrier Outdoor units on rooftops and utility/traffic poles in key right-of-ways, an operator is able to lower its network operating expenses. The Hi-Power Carrier Outdoor small cells constitute about 12-15% of total Carrier Outdoor units. For example, several hundred outdoor small cells that Sprint deployed in NYC are compact 2x20W radios that can cover significant coverage areas in dense urban locations. With its compact size and high output power, the Hi-Power Carrier Outdoor small cells will remain critical network element for many operators as they densify in urban centers where siting challenges remain significant and in rural areas where cost-effective solution other than Macro is required to make the economics work.



Source: Mobile Experts

Chart 40: Carrier Outdoor Small Cell Shipment Forecast, by Power, 2017-2023

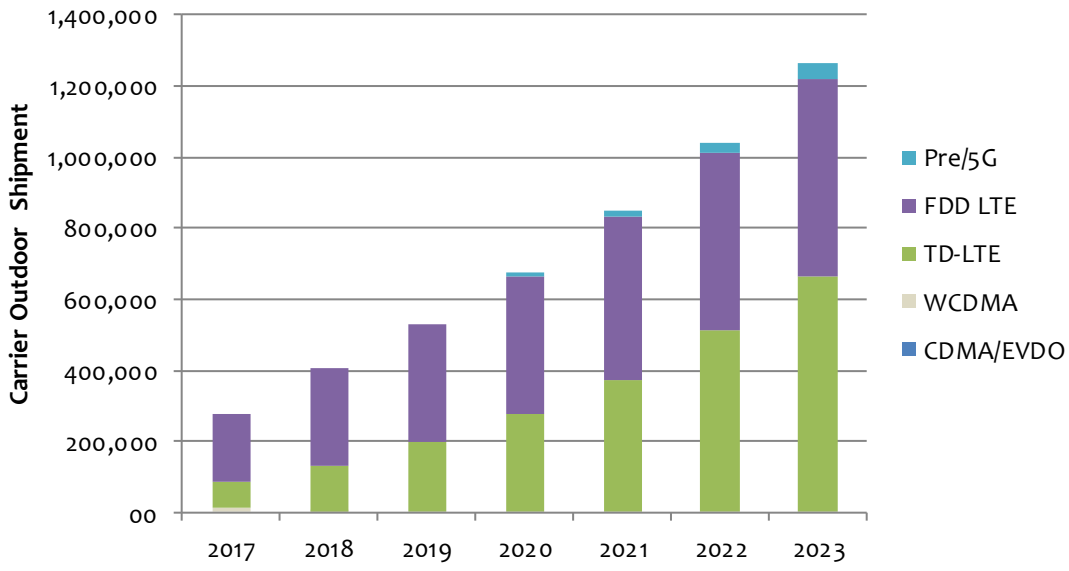
Carrier outdoor applications will increasingly adopt the Centralized RAN architecture with low power RRHs extending mobile coverage and capacity where they are needed. As operators contemplate optimal RAN architecture for 5G services with much higher fronthaul and backhaul bandwidth requirements, Split Baseband RRHs will be more widely deployed as compared to traditional CPRI interface. Meanwhile, "all in one" Integrated outdoor small cell units will be deployed in areas where ease of installation is paramount, and interference with the macro layer is less of an issue. For example, we forecast all Hi-Power Carrier Outdoor small cells in our forecast are integrated units with baseband and radio in one tightly integrated unit. Unlike While some portion of DRS systems are deployed outdoors, we have lowered our projection of "outdoor" DRS radio units in hardened enclosures. As a result, our forecast of Carrier Outdoor small cells has come down meaningfully from our initial 2017 forecast.



Source: Mobile Experts

Chart 41: Carrier Outdoor Small Cell Shipment Forecast, by Fronthaul/Backhaul, 2017-2023

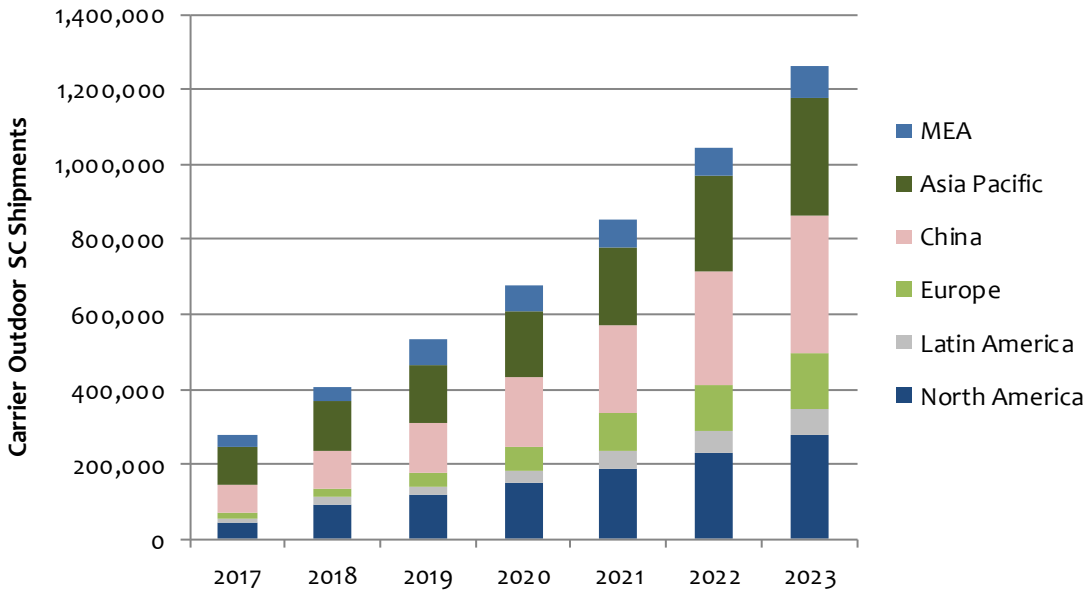
As mobile operators densify their LTE networks, FDD and TD-LTE interfaces are expected to dominate air interface technology share for Carrier Outdoor units. Moreover, 5G outdoor units in the form of low power RRHs is expected to ramp up starting in 2020 as 5G trials lead to commercial deployments. It should be noted that most of the 5G low power RRHs in our forecast will come from 5G RRHs operating in the C-band (mostly in China and APAC). The 5G RRH units operating in the millimeter wave bands, for example, those being deployed for Verizon's 5G Fixed commercial launch in the second half of this year are actually high-power units, and hence, is not reflected in this Small Cells forecast. (All 5G RRHs including High and Low Power units are reflected in our 5G RRH Report.)



Source: Mobile Experts

Chart 42: Carrier Outdoor Small Cell Shipment Forecast, by Air Interface, 2017-2023

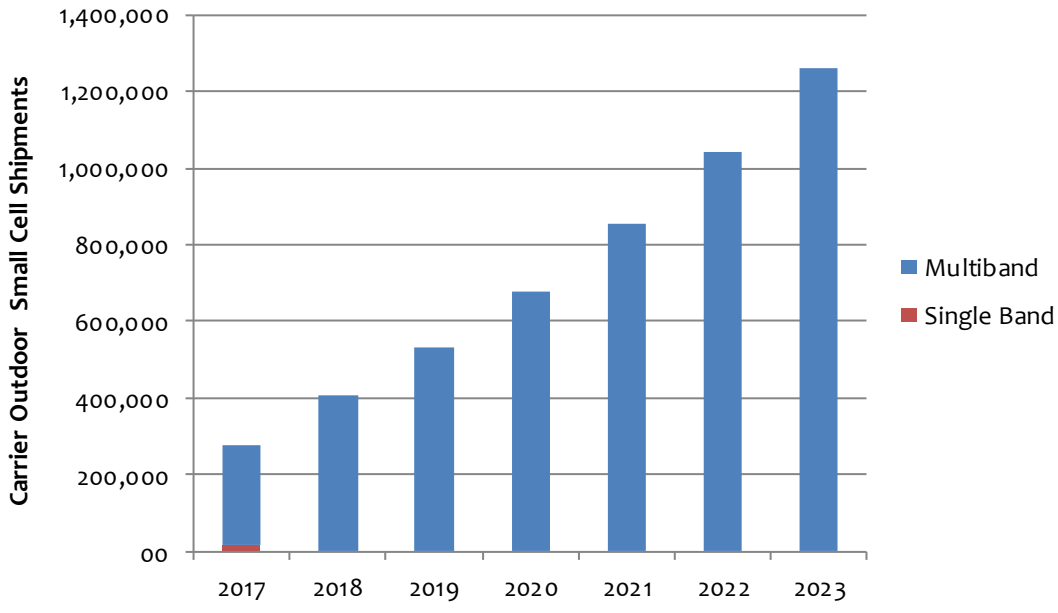
The North American market is expected to be a key segment for carrier outdoor deployments in 2018, as all four operators look to increase their network investments this year. As the smallest of the four major mobile operators in the USA, Sprint is looking to leverage outdoor (and indoor) small cells to reduce ongoing operating expenses such as site lease and backhaul. Sprint is trying out innovative approaches like placing small cells on top of relatively tall poles along right-of-ways to minimize the number of sites required, and associated lease costs. Where fiber access is limited, Sprint is exploring wireless backhaul options via Magic Box leveraging its spectrum-rich position in the 2.5 GHz band. Also, CBRS is expected to provide some tailwind as operators look to leverage the additional 3.5 GHz band in their network densification strategies. Outside of the USA, China and India continue to be big markets for outdoor small cells. Non-leading mobile operators like China Unicom and others in respective markets are looking for ways to reduce network operation expenses such as siting and backhaul, and are seeking macro-like small cells to challenge the incumbents.



Source: Mobile Experts

Chart 43: Carrier Outdoor Small Cell Shipment Forecast, by Region, 2017-2023

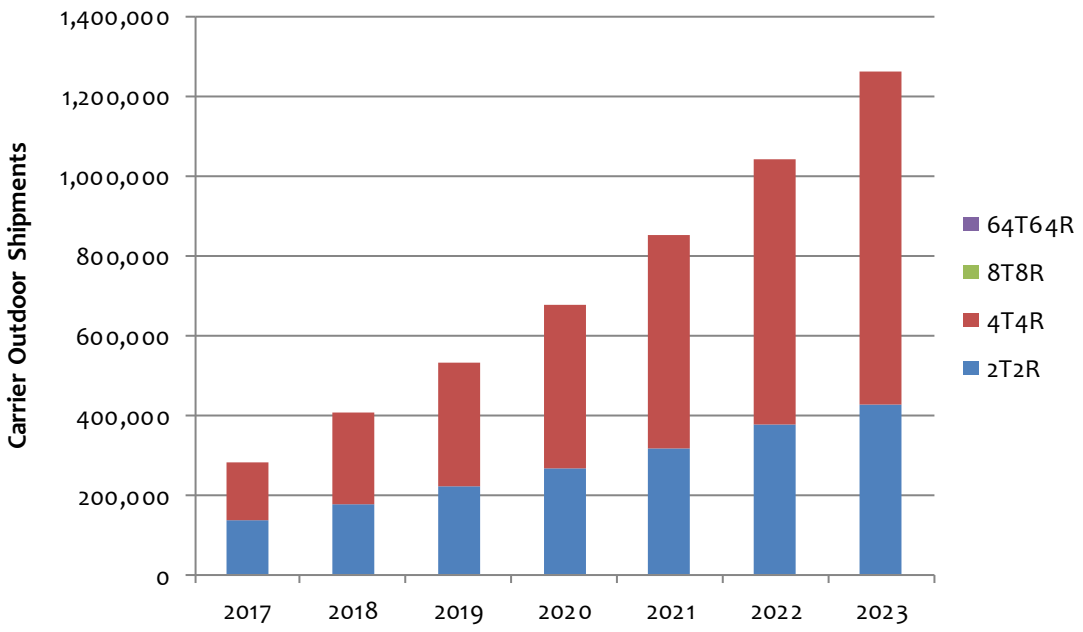
For outdoor applications, multiband support is critically important. A wide variety of 3G and LTE devices will need to be supported across multiple frequency bands. Most outdoor small cells already support multimode, multiband support as this trend is a "table stake" in the marketplace.



Source: Mobile Experts

Chart 44: Carrier Outdoor Small Cell Shipment Forecast, by Multiband Type, 2017-2023

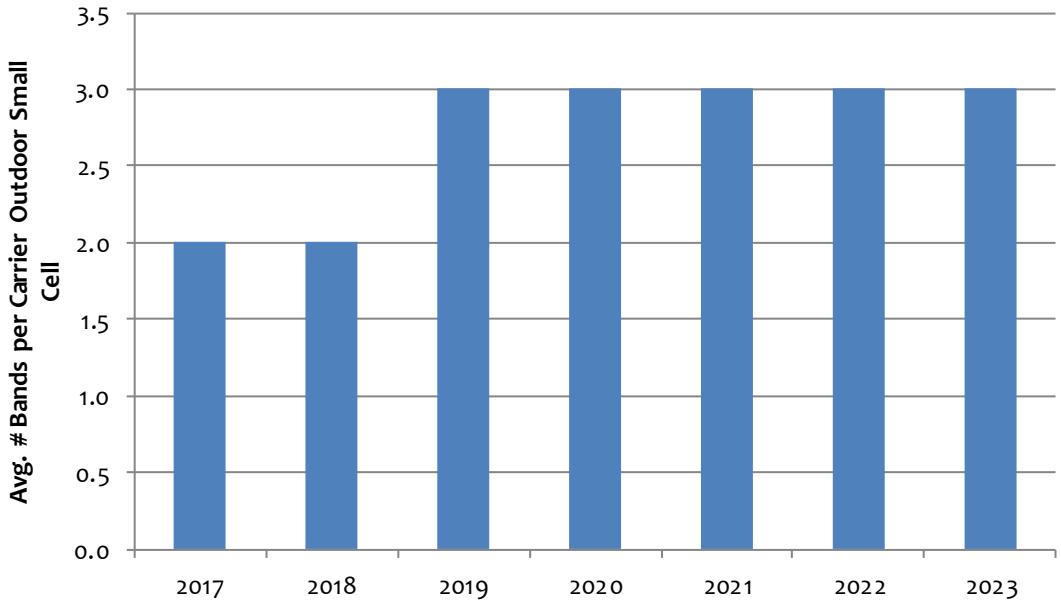
Carrier Outdoor units are highly capable small cells with macro-like features such as high RF power, high user capacity, multimode/multiband support, etc. Many outdoor RRH units today support 4T4R, and 8T8R antenna configuration are also supported in some Macro units. As noted earlier, with the 5G RRH units operating in the millimeter wave band now classified as "High Power" RRH, they are no longer counted in this Small Cell report. Based on product announcements at MWC 2018, the initial Low Power 5G RRHs (counted in this Small Cells report) operate in the C-band. These units support 4T4R. Hence, high antenna configuration commonly associated with the millimeter wave band operation are found in Macro category today. Thus, 4T4R configuration will be the dominant antenna configuration for the Carrier Outdoor small cells, even the initial low power 5G RRHs.



Source: Mobile Experts

Chart 45: Carrier Outdoor Small Cell Forecast, by Antenna Configuration, 2017-2023

With many outdoor units supporting dual-band carriers, Mobile Experts predicts the average number of bands per Carrier Outdoor unit to increase over time from 2 to 3 by 2023. With some units supporting multiple RF modules that can be customized for licensed LTE (FDD or TDD), unlicensed Wi-Fi, and LAA, operators can aggregate multiple carriers to increase peak data rates and throughput capacity.

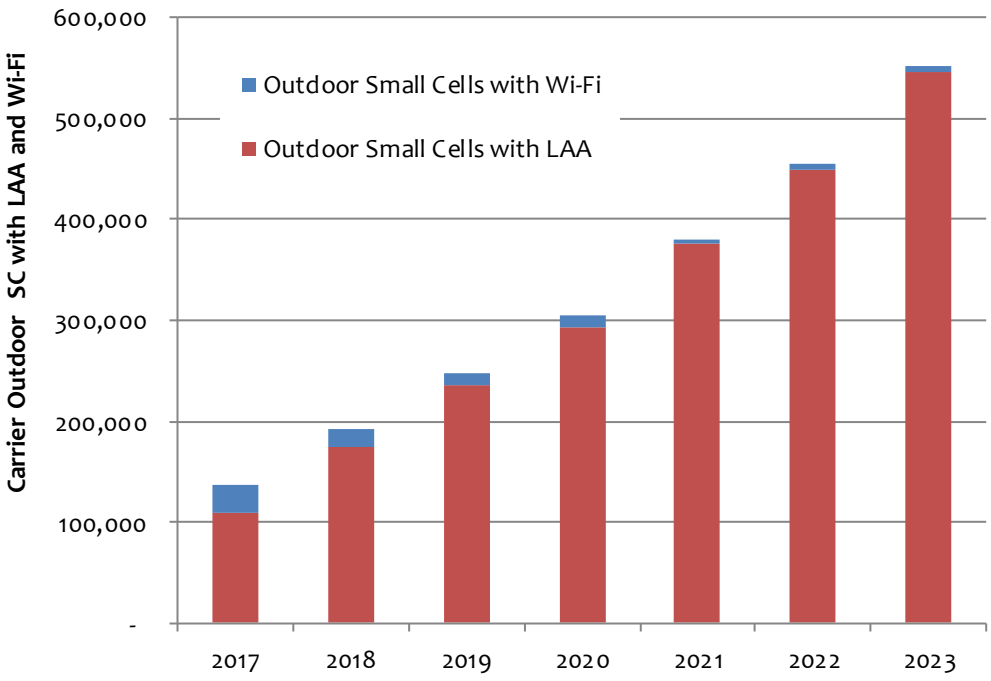


Source: Mobile Experts

Chart 46: Avg. # of Bands per Carrier Outdoor Small Cell Unit, 2017-2023

With more seamless network service integration with LAA over the 5 GHz unlicensed spectrum band, Mobile Experts predicts a high attach rate of LAA for carrier outdoor units versus indoor ones as operators have a better control of where and how the 5 GHz unlicensed spectrum will be leveraged with LAA in outdoor applications. Since most of Wi-Fi usage indoors is confined to inside of homes and commercial buildings, the noise floor of the 5 GHz band in dense urban areas is expected to be relatively low. Because of this, we expect the mobile operators to leverage LAA more extensively in outdoor applications since they can operate LAA in a "cleaner" environment with relatively high power small cells (higher than 50-100mW consumer-grade Wi-Fi units inside buildings).

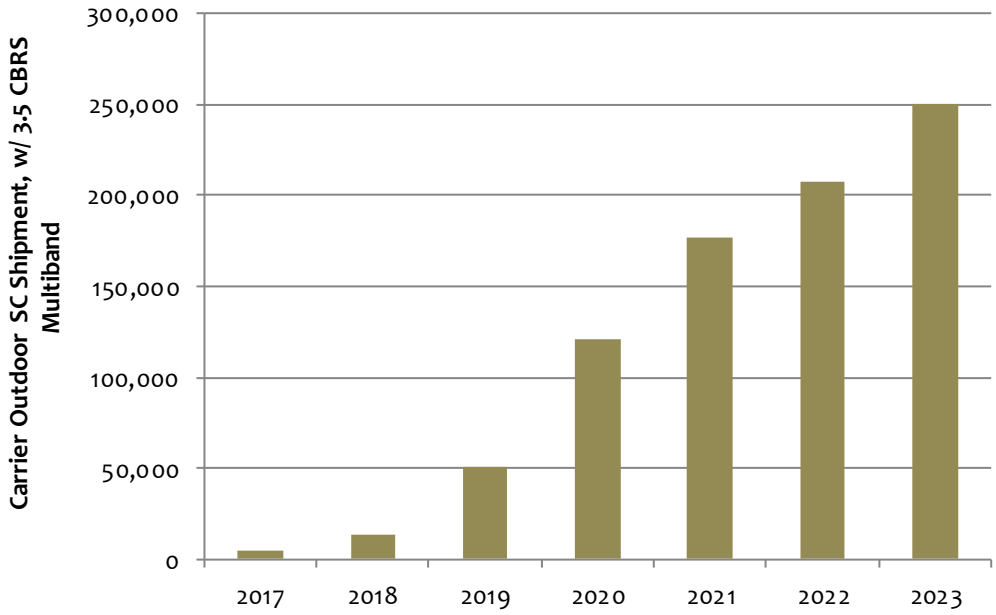
As LAA adoption increases, the need for Wi-Fi integrated small cells will decline. For applications where operators are required to install W-Fi (e.g., to fulfill municipality agreement to provide WI-Fi coverage in parks in exchange for siting), they may simply opt for standalone Wi-Fi access points. Where siting, power, or backhaul is limited, the operators will adopt Wi-Fi integrated multiband small cells. We expect these use cases will be limited. In the end, Wi-Fi use by mobile operators is becoming less relevant. While LAA remains attractive in providing high peak speeds, its attractiveness is largely confined to spectrum-constrained markets like North America and parts of MEA. For example, with a rich trove of licensed spectrum, there is almost no demand for LAA in China.



Source: Mobile Experts

Chart 47: Carrier Outdoor Small Cell Forecast, with LAA and Wi-Fi, 2017-2023

Meanwhile, mobile operator plans for the 3.5 GHz CBRS remains robust. Verizon and T-Mobile have been very public about their enthusiasm to leverage this newfound spectrum to enhance their network capacity. Mobile Experts predicts the attach rate of 3.5 GHz CBRS multiband support to reach over 200K units by 2023. With multiple spectrum options at their disposal including AWS-3, WCS and 5 GHz unlicensed with LAA, the mobile operators in the USA have multiple ways to achieve wireless capacity expansion. With major operators' support for this band, we expect major Tier 1 handset vendors to introduce marquee smartphones supporting this band in 2019 and expect small cell shipments to coincide with this timeline as shown below.

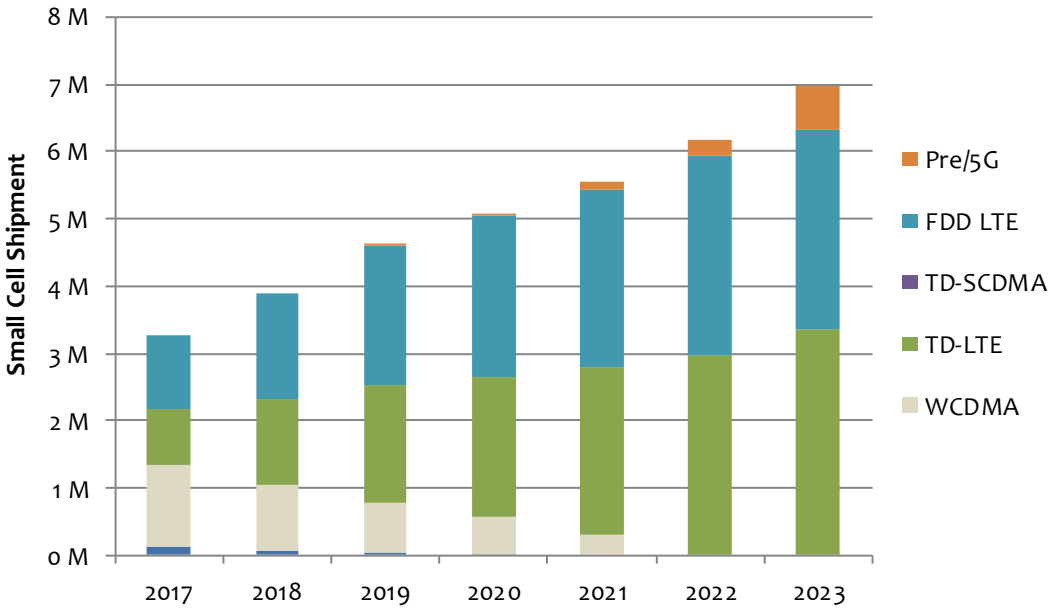


Source: Mobile Experts

Chart 48: Carrier Outdoor Small Cell Forecast, with 3.5 GHz CBRS Multiband, 2017-2023

Forecast by Air Interface Technology

The small cell share breakdown by air interface technology shows a shift from 3G WCDMA to LTE. This shift reflects a transition from residential-grade small cells to carrier-grade units supporting advanced LTE features such as carrier aggregation and 4T4R to achieve greater spectral efficiency. The carrier indoor and outdoor small cell market has quickly transitioned to LTE. Mobile Experts predicts 5G small cells in the form of DRS radio units for indoor, operating in the C-band to ramp up earnestly in 2021 as 5G DRS units replace installed base of LTE units. The leading 5G deployments in North America is expected to be largely in the Macro category with high-power RRHs and compact Macro units leveraging massive MIMO and the millimeter wave bands.

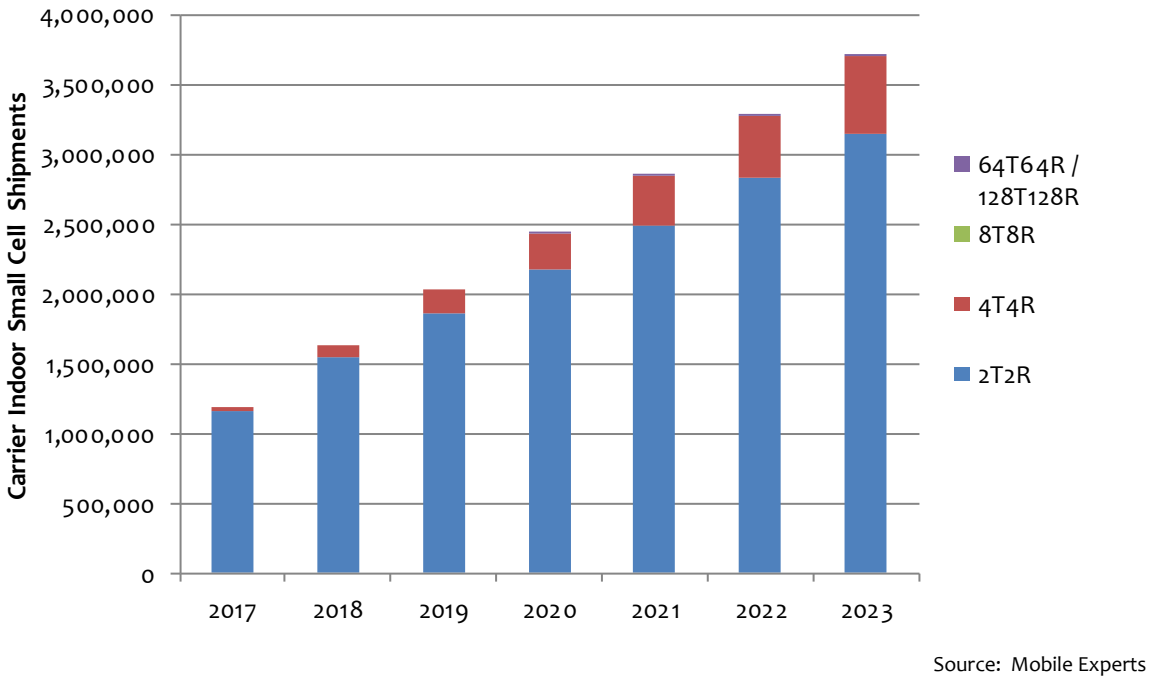


Source: Mobile Experts

Chart 49: Small Cell Shipments, by Technology, 2017-2023

Forecast by Antenna Configuration

As the small cell market shifts away from residential femtocells to carrier-grade units encompassing high-performance LTE features like carrier aggregation, multiband carrier support, small cell units will increasingly adopt higher order antenna configurations from 2T2R to 4T4R. While we had expected some millimeter wave band RRH units to be "low power" (i.e., less than +52 dBm EIRP), semiconductor technology has advanced to allow higher power using Massive MIMO. The result is that most 5G millimeter wave units expected to be deployed in the next few years are now expected to be "high power," higher than +52 dBm. (see the Mobile Experts Macro Base Station forecast.) Thus, our Small Cells forecast mostly capture 4T4R units. This market is still changing, so our current definition of "high power" (shooting as far as possible) may change as the industry aligns around specific use cases. (We realize that the terminology is confusing… for example, one of the major vendors shows a millimeter wave base station product employing massive MIMO output power of +53 dBm EIRP as a "5G outdoor small cell.")

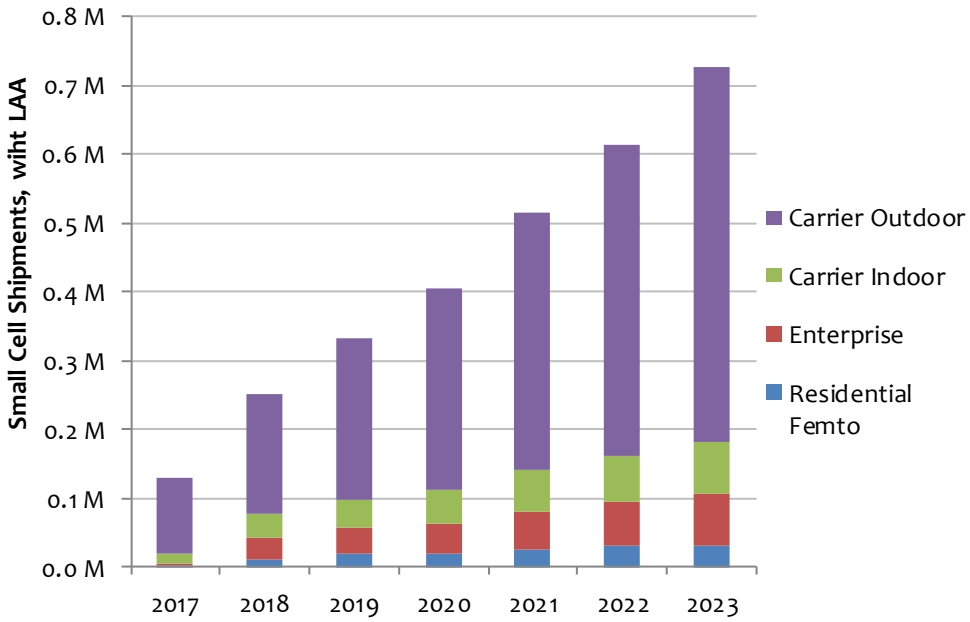


Source: Mobile Experts

Chart 50: Small Cell Shipment Share, by Antenna Configuration, 2017-2023

Forecast for LAA Radios in Small Cells

Carrier aggregation of licensed and unlicensed bands through LAA is expected to provide additional capacity boost for mobile operators seeking to claim "Gigabit LTE" services. For spectrum-constrained operators, LAA offers seamless way to aggregate unlicensed spectrum with a licensed carrier to boost user speeds and increase network capacity. We have been forecasting down the volume of LAA multiband small cells through our quarterly forecast updates in the past year to account for limited appeal of this feature to certain markets. For example, there is a scant demand for LAA in China where the operators have abundant licensed spectrum. We believe LAA will appeal to operators in North America and parts of Europe and MEA where licensed spectrum per operator is limited. The ramp has been slower than anticipated as LTE-U and LAA trials have taken a lot longer, and LAA-capable user devices are just now coming to the market. We forecast the LAA small cells to reach just over 450K annual shipment in 2023.

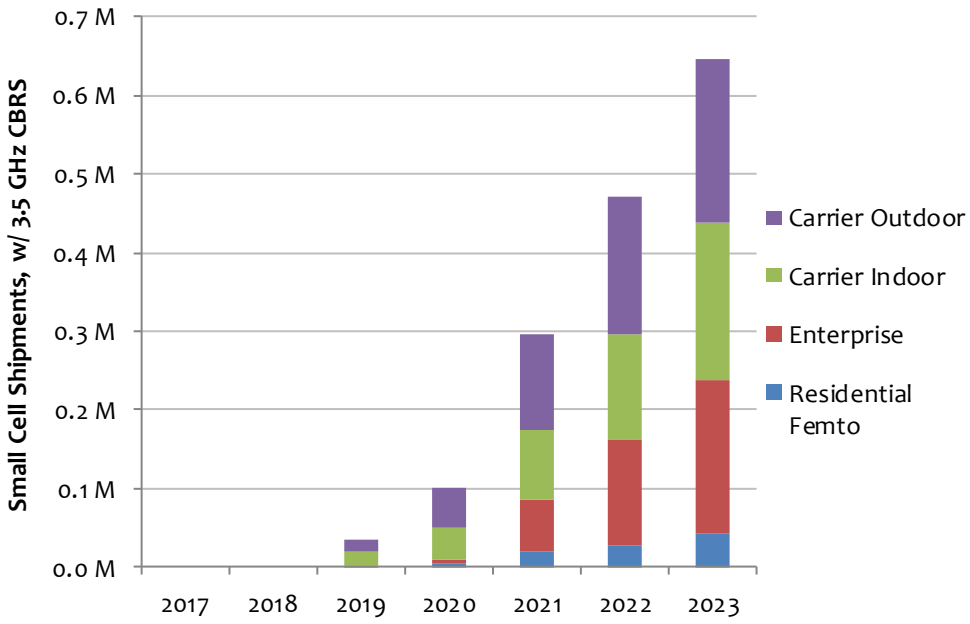


Source: Mobile Experts

Chart 51: Small Cell Shipment, with LTE-U/LAA, 2017-2023

Forecast for 3.5 GHz CBRS Radios in Small Cells

The 3.5 GHz CBRS ecosystem is still in early stages. While the regulatory process of certifying SAS and ESC suppliers and final rulemaking on spectrum term duration and spectrum geographical size has drawn out, the ecosystem partners have been fine-tuning their product solutions and business models. With the strong support from the mobile operator community, we now believe that Tier 1 handset vendors will introduce CBRS smartphones in 2019, and the commercial service to launch late 2018 and volume equipment sales in 2019. Our forecast assumes that mobile operators will largely focus on CBRS outdoor deployments while enterprises and neutral host providers to focus on indoor deployments. If cable operators jump into wireless market with a serious way with heavy network investments, we would expect Residential femtocell and Carrier Indoor as well as Carrier Outdoor categories to jump higher than our current forecast.

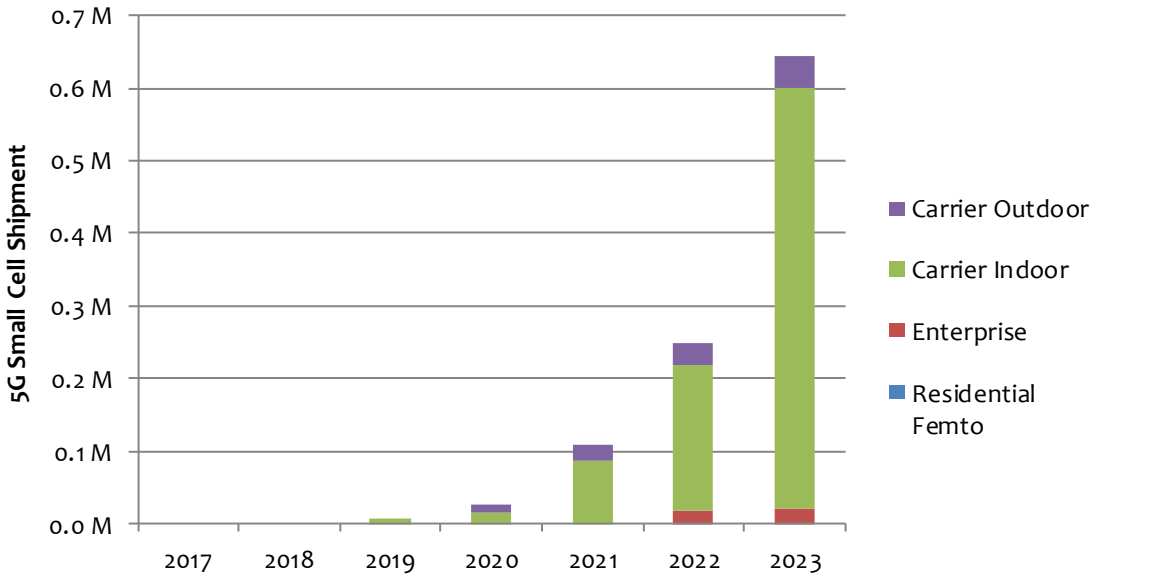


Source: Mobile Experts

Chart 52: Small Cell Shipment, with 3.5 GHz CBRS Radio, 2017-2023

5G Small Cell Forecast

The initial 5G network investment across mobile and fixed wireless application will be Macro radios. High power RRHs and "all in one" integrated base stations operating at both the 3-4 GHz mid band and the millimeter wave band with massive MIMO will operate at high power (greater than +52 dBm EIRP for massive MIMO array radios). The initial 5G small cells will be mostly DRS indoor units for China and some low power RRH units operating in the C-band will be used for small cell densification of traffic hotspot locations. Most of the initial millimeter wave, massive MIMO radios are expected to operate at "macro" RF power level between +56 dBm and +60 dBm. Hence, these units, some of which are expected to be deployed for 5G Fixed services are excluded in the "5G Small Cell" forecast below.

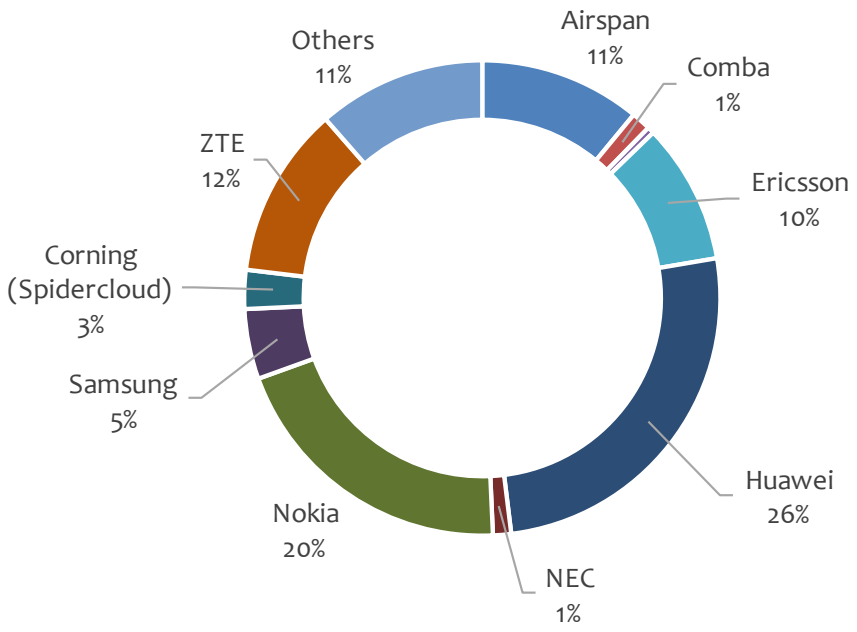


Source: Mobile Experts

Chart 53: 5G Small Cell Shipment, 2017-2023

6 MARKET SHARES

The small cell market grew 27% year over year to over $2.8B in 2017. In 2016, we saw major Tier 1 infrastructure vendors leveraging their macro footprint and customer account relationships to extend their carrier small cell products deep into Tier 1 mobile networks. Meanwhile, select enterprise-focused small cell vendors who have years of experience working with Tier 1 operators through the product approval process, have captured niche market segments and are looking to expand their footprint. Overall, the market is expanding for those who have established themselves in the marketplace including all Tier 1 infrastructure vendors and a select group of smaller players. Nokia, Ericsson, ZTE, and Airspan notably grew their market shares. With strong performance in Carrier Outdoor units carrying higher ASP, Nokia outpaced the market with strong year-over-year growth in unit shipments in Carrier Outdoor products. Meanwhile, Ericsson found success with its Radio Dot product which experienced a strong year over year growth. As a smaller nimble player, Airspan found success with a portfolio of Carrier Indoor small cell products at Jio and Sprint.



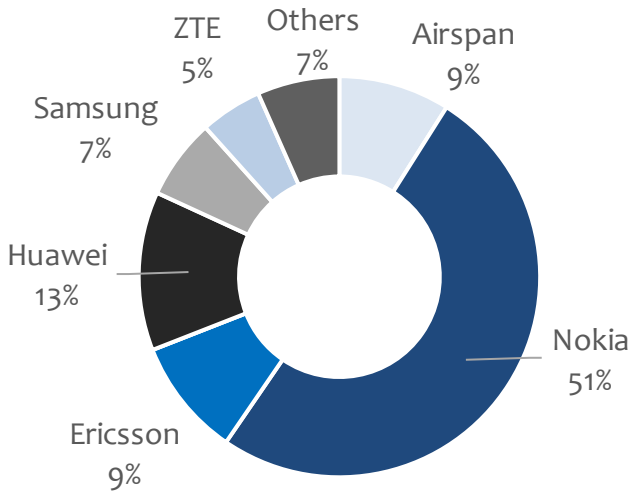
Source: Mobile Experts

Chart 54: Market Share by Revenue for Small Cells, 2017

Market Shares for Carrier Outdoor

Every major infrastructure OEM vendor has an outdoor small cell offering. In general, these Tier 1 OEMs have market advantage in extending their macro footprint to provide

"macro parity" network management control and operational familiarity to carrier customers. For example, Huawei has been successful in leveraging its broad macro network footprints across China and APAC to sell through its LampSite small cell product. Nokia likewise has been quite successful in leveraging its "macro parity" features of its small cell offerings to meet specific market requirements. Airspan has defied a general industry norm and has established a foothold in the Carrier Outdoor market with its strategic supplier relationship in Reliance Jio's LTE network rollout, and as we had predicted, captured market share in North America with Sprint Magic Box win. With strong wins in North America and Japan with its high-power Mini Macro small cell product, we estimate that Nokia holds about 50% market share in the Carrier Outdoor small cell segment. One significant change in the market share estimate of Carrier Outdoor shipments is the significant change to how we account "outdoor" DRS units. Compared to last year, we are now counting most of DRS units as Carrier Indoor small cells based on market update from the leading DRS vendors who now report that most of DRS units are for indoor applications.

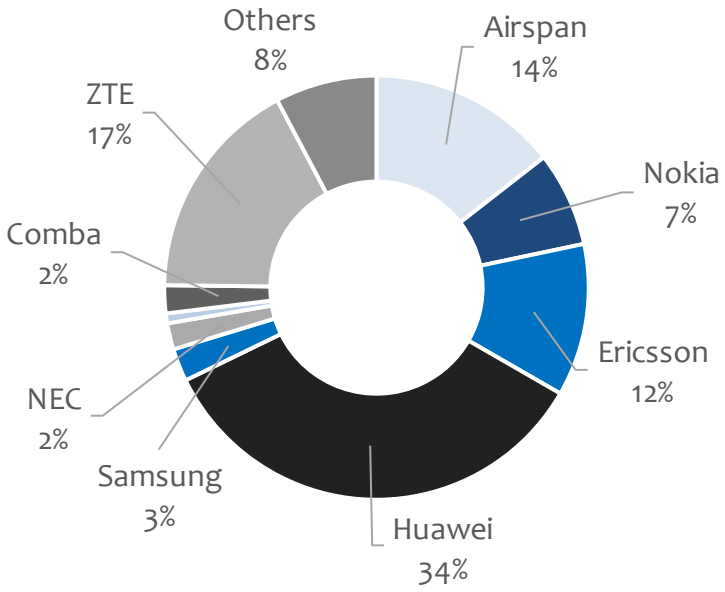


Source: Mobile Experts

Chart 55: Market Share for Carrier Outdoor Small Cells, 2017

Market Shares for Carrier Indoors

Huawei still leads the Carrier Indoor segment despite losing some market share. Notable market share takers were Airspan with its UE Relay product (more commonly known as "Magic Box" – the product name assigned by Sprint) and ZTE which saw a meaningful jump in shipments in China in 2017. Ericsson also saw a strong jump in its Radio Dot business in 2017.

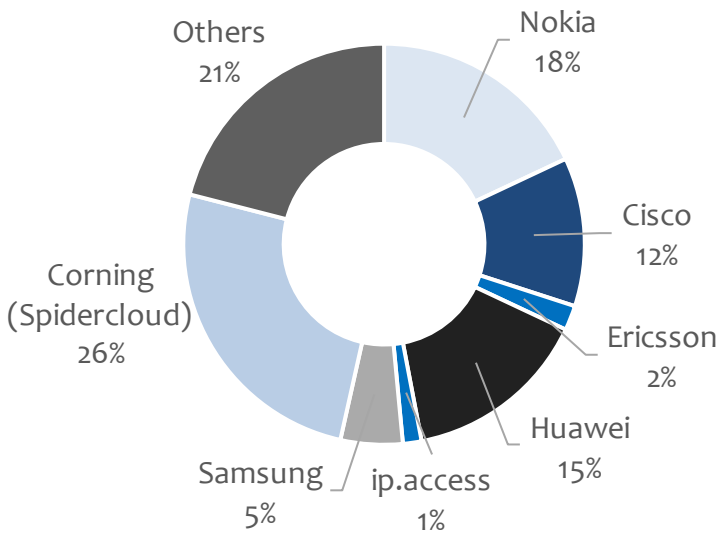


Source: Mobile Experts

Chart 56: Market Share for Carrier Indoor, 2017

Market Shares for Enterprise Small Cells

The enterprise segment is differentiated from the carrier indoor segment as enterprises have different priorities and requirements. However, carriers demand the same rigor in their approval process as they don't want any enterprise small cells to affect their macro network performance. This is a tough market. A success in this market segment requires OEM vendors to satisfy both the operators and enterprises. It is a challenging segment to succeed in, but some notable players have found market traction with tier 1 operators and certain enterprise channels. The major OEMs will also have a share of this market, but only for those vertical segments where "macro parity" is essential. With Tier 1 vendors largely focused on Carrier Indoor and Outdoor segments, not much has changed in 2017. The enterprise market remains a tough segment to crack. Some smaller players are focusing on vertical IoT segments to differentiate their products rather than focus on typical broadband use case which will require arduous operator approval process which can take multiple years and heavy investment that may not pay out.

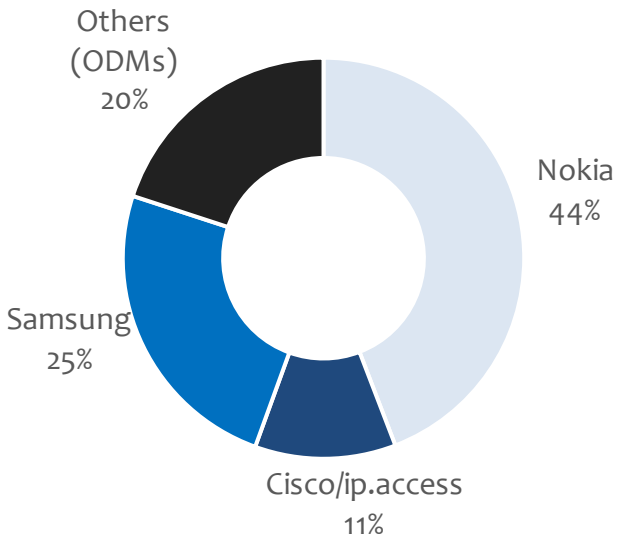


Source: Mobile Experts

Chart 57: Market Share for Enterprise Small Cells, 2017

Market Shares for Residential Femtocells

The residential femtocell market is a low-margin, high-volume business. We have seen several companies drop out. It is hard for any OEM vendor to solely focus on this segment for a sustainable business. Many of the leaders in this segment have other business lines to help subsidize this effort. Some established players like Samsung and Nokia view this segment as an opportunity to pursue other high-margin segments such as carrier-grade small cells, and ultimately Macro radios which is the ultimate prize. Nokia and Samsung have long-standing carrier relationships with Tier 1 operators in North America to provide 3G/LTE femtocells, and Mobile Experts expects the trend to continue.



Source: Mobile Experts

Chart 58: Market Share for Residential Femtocells, 2017

7 COMPANY PROFILES

ACCELLERAN:

Accelleran is a small cell OEM start up based out of Belgium focusing efforts to produce LTE TDD small cells, targeting both licensed bands and shared 3.5GHz CBRS band for the US. At the MWC 2017, the company released its CBRS small cell based on Cavium SoC. The company has a few trials ongoing with cable and OTT operators in the US to pursue potential market opportunities leveraging CBRS. www.accelleran.com

AIRHOP:

AirHop Communications is a San Diego based company providing SON solutions for dynamic resource optimization and network management of heterogeneous networks. Founded in 2007, the company's SON solutions have been incorporated in several small cell deployments. www.airhopcomm.com

AIRSPAN:

Airspan Networks has developed a line of LTE small cells, including indoor enterprise units and outdoor units with integrated wireless backhaul. The company introduced LTE Relay system to boost network efficiency at cell edge. The company has deployed tens of thousands of small cells in India, as well as successful relationships with Softbank in Japan and with Sprint in the US. With successful small cell deployments, the company has tripled its employee base to pursue growing opportunities in North America, APAC, and MEA. www.airspan.com.

ALTIOSTAR:

Altiostar has developed a split-baseband LTE RAN product line, which they are targeting at macro and small cell deployments. The company has set up a proprietary baseband partition in which the scheduler sits in the radio head, allowing higher latency in the transport and much lower bandwidth for lower transport cost. The company has announced its virtualized RAN solution and is conducting lab trials with few tier-one operators, including SK Telecom. The company recently announced a couple of partnerships with DAS vendors to apply its virtualized RAN solution to reduce fronthaul bandwidth requirement in DAS system deployments to support higher capacity requirements of LTE and upcoming 5G. www.altiostar.com

ARGELA:

Argela has close connections with Turkish mobile operators. As a part of Turk Telekom Group, Argela has a more direct route to market than other femtocell suppliers. The company recently demonstrated its ProgRAN solution that encompasses the programmable RAN solution based on the NFV/SDN principles. The platform was based on Cavium's baseband processor. www.argela.com

BAICELLS:

Founded in 2014, Baicells is a privately-held company based in Beijing, China. The company's product solutions range from indoor and outdoor small cells, CPEs, and antennas. With a new sales office in the US, the company is expanding into unlicensed and shared spectrum opportunities with cable operators and neutral host providers. The company announced its 'NeutralCell' small cell product at MWC 2017 leveraging 3.5 GHz CBRS. www.baicells.com

BENETEL:

Based in Dublin, Ireland, Benetel is a system design house focusing on small cell design and development. The company has a portfolio of baseband and RF modules and works with leading OEMs for custom design and development projects. The company's new design center opening in Poland may portend small cell market growth and market requirements for low-cost development and fast time-to-market production. www.benetel.com

BRAVOCOM:

BravoCom is China-based communication technology vendor with early history of developing small cell products for the Chinese domestic market. It has similar small cell products like those of Huawei's Lampsite and Ericsson Dot. www.bravocomtech.com

BROADCOM:

Broadcom has grown their presence in small cells over the past few years, with very low power consumption in the PHY processing for a multimode small cell, as well as growing market share in the residential femtocell segment. The company had jumped ahead of competition in the enterprise small-cell segment with major wins at Cisco/SpiderCloud and early design wins for LTE small cells at KT, SK Telecom, and others. Their design touting low power consumption and a mature stack had been a key differentiator. After the Avago merger, the company has decided to exit the small

cell SoC market. While the company continues to ship small cell SoC for existing commitments, Mobile Experts expect the production to stop in 2017. www.broadcom.com

CASA SYSTEMS:

Headquartered in Andover, MA, Casa Systems was founded in 2003 with core business in cable broadband and video product solutions. The company has since expanded its product solution portfolio to include wireless products addressing carrier Wi-Fi and small cell products. The company recently announced customer wins at China Mobile, Telefonica Spain, and Sprint for its small cell and small cell core gateway products. The company has about 600 employees and more than $300M in annual revenue, mostly from its core businesses in cable broadband and video. www.casa-systems.com

CAVIUM: (TO BE ACQUIRED BY MARVELL)

As an established chipset supplier in Layers 4-7 for 3G core networks, Cavium started in a difficult position, but has emerged as a strong contender for Layers 1-7 by combining up to 48 processor cores and 2.5 GHz clock speeds in some very high-performance SoCs. The key to the Cavium approach is to build in enough horsepower and memory that data flows through accelerators and processors without copying to memory, for an efficient solution. Cavium penetrated the early market in Korea with large volume shipments of carrier-grade small cell SoCs, but more recently has been focused on an innovative strategy for virtualization, to support CRAN in split-baseband product configurations. With Broadcom's exit from the small cell SoC market, the company has gained few additional customers and design wins. The company continues to invest in LTE baseband market as this effort can largely leverage the company's main investment in processor technology. www.cavium.com

CISCO:

Cisco's global footprint and channel sale partnerships especially in enterprise IT segment bolds well for its small cell solutions. Cisco has been working to arrange the business conditions for mobile operators and enterprises to support the upgrade from Wi-Fi to licensed/unlicensed operation. Endorsements from several tier-one mobile operators including Vodafone and EE have validated the Cisco enterprise approach. Cisco's strategic partnerships with SpiderCloud for enterprise small cell segment and also with the larger Ericsson partnership bolds well for its wider aspiration to increase share in the service provider segment, and small cell is expected to be a meaningful part of its offering to service providers. Cisco's "direct-to-enterprise" small cell strategy appears to have changed recently, as it plans to open its clip-on interface to

small cell partners instead. Cisco's wireless strategy is still largely planted in Wi-Fi and IEEE 802.11 roadmap. www.cisco.com

CLEARSKY TECHNOLOGIES:

This Florida-based company provides hosted infrastructure and services to tier-two and tier-three mobile operators, primarily in the US. The company has recently announced its contract with GCI, a leading mobile operator in Alaska, to provide a complete small cell as service solution offering. www.csky.com

COMBA TELECOM:

Comba holds a strong position in supporting coverage solutions in China, as well as a few South Asian and Latin American markets. The company supplies a wide range of repeaters, DAS radio heads, TMAs, residential and indoor small cells, and other coverage related products. Comba has been highlighted recently as the first supplier of a "nanocell" for TD-LTE trials for China Mobile. www.comba-telecom.com

COMMSCOPE:

Commscope is a global leader in fiber connectivity and DAS systems whose IPR and product portfolios in in-building wireless space were expanded with acquisitions of TE Connectivity and Airvana. With the Airvana acquisition in 2015, Commscope has formally introduced a small cell product based on Airvana's OneCell. The OneCell concept combines aspects of small cells, DAS, and Cloud RAN to create a flexible in-building solution that can dynamically allocate capacity throughout a building, while avoiding some of the high-cost items associated with DAS, and providing CRAN features such as CoMP and eICIC. Commscope's LTE/Wi-Fi small cell has been adopted by Sprint for indoor deployment. www.commscope.com

CONTELA:

Contela provides femtocells and related gateways for the Japanese and Korean markets, and has ramped to significant volume with more than 80,000 LTE small cells for SK Telecom. The company has been able to successfully penetrate at least two major customers outside of the Korean market, with significant shipments during 2015. www.contela.com.kr

CROWN CASTLE:

A traditional wireless tower company that is taking a more active role in the small cells infrastructure business. The company has made several fiber acquisitions in the US to bolster its small cells business by offering both backhaul transport (primarily dark fiber) and site leases for mobile operator customers to deploy small cells or outdoor DAS remote radio heads in key markets. The company's wireless infrastructure consists of 40,000 towers and 17,000 route miles of fiber. As of 2016, the company reports that its small cell infrastructure business now make up about 10% of its total business. www.crowncastle.com

ERICSSON AB:

Ericsson showed up late to the small cell party, but they quickly took a leadership position in high-end small cells. The RBS6402 product incorporates 10 frequency bands with up to four running simultaneously, as well as integrated dual-band Wi-Fi. By offering a standard product with carrier aggregation and macro parity, Ericsson has established a gold standard in the high-end small cell market. Ericsson also offers the "Radio Dot" product as an approach for medium-sized enterprises. Ericsson's biggest move in the small cell market came with the news of its acquisition of BelAir Networks in March 2012. The combination of strong Carrier Wi-Fi and licensed-band small cell capability puts Ericsson in position to support converged small cells. With the recent Ericsson re-organization in March 2017 and ongoing Cisco partnership, it remains to be seen whether there will be a focused organizational business unit dedicated to small cell products (similar to Huawei's). www.ericsson.com

EXTENET SYSTEMS:

Extenet Systems is a privately-held wireless infrastructure provider of distributed networks. As a part of broader Digital Bridge holdings, the company designs, owns, and operates neutral-host networks leveraging multiple technologies including small cells, Wi-Fi, RRH, DAS, and other technologies on behalf of mobile operators and enterprise customers. The company recently partnered with Verizon to build out some of Verizon's small cell deployments in the San Francisco Bay area. The company has ongoing projects with many of tier 1 operators in the United States. www.extenetsystems.com

GOOGLE (ALPHABET):

With its core business of Internet search/advertising today, it may seem odd to put Google on our list of small cell company profiles. With its many wireless and telecom related activities, however, we have decided to put a placeholder here to signify the

possibility of Google's influence in the small cells marketplace especially in light of its significant policy and ecosystem development efforts in the 3.5GHz CBRS space as well as other wireless/telecom initiatives already in progress, including Google Fiber, Google Fi, millimeter wave experimental trials, and not to mention its heavy influence in the device ecosystem with Android. www.google.com

HUAWEI TECHNOLOGIES:

Huawei is a shipment leader in non-residential small cells with success of its LampSite product line. The first two generations of LampSite, which can best be described as a low power RRH product with distributed RF, has been hugely popular in China and Southeast Asia. The product provides flexible indoor coverage/capacity solution with 'macro parity' features so that operators can reduce operational and management costs associated with running multi-layer networks. The company has focused its efforts on multi-band small cells for higher capacity carrier applications. With the next-generation LampSite, Huawei is targeting other regions including Europe where RAN sharing is more common. www.huawei.com

INNOWIRELESS (QUCELL):

Based in Korea, Innowireless provides network testing and optimization solutions. Most of their revenue is derived from testing/optimization services in North America. The company delivered tens of thousands of small cells to Korea Telecom for their LTE capacity upgrades during 2012 and 2013, acting as an ODM with a Cavium chipset and using software developed by third parties and by KT themselves. Recently, the company, under the "Qucell" brand, has been introducing both FD-LTE and TD-LTE residential, indoor, and outdoor small cells based on Qualcomm chipset to KT, Fujitsu and others. www.qucell.com

INTEL:

Intel acquired Mindspeed in early 2014, combining the Intel strategy of network processing for Cloud RAN applications with the Mindspeed Transcede and Picochip femtocell products. Intel's open SoC platforms should lend themselves to split-baseband architectures, as well as low power small cell implementation. Beyond the past success of Mindspeed SoC at Contela and others, Parallel Wireless and ip.access are key OEM partners for Intel in introducing small cell solution leveraging Intel Transcede SoC solution. www.intel.com

IP.ACCESS:

Femtocell vendor ip.access has successfully penetrated the enterprise and rural/remote markets, as well as its longstanding residential success with AT&T Wireless and a few other mobile operators. With a recent investment from a private equity and several product introductions, including LTE access points covering more frequency bands to cover more markets, and the Viper platform to ease the enterprise small cell deployments, the company is looking to accelerate its growth. In a competitive marketplace with similar marketing messages around virtualized RAN with ease of deployments, it will likely come down to robust product features and tactical executions. www.ipaccess.com

JUNI:

With a research and development center in Korea, Juni has been developing LTE small cells based on Intel platform since 2009. It is focusing on CBRS market and has a trial ongoing in this space. www.juniglobal.com

NEC:

NEC has successfully deployed significant numbers of indoor and outdoor small cells for Softbank and other operators in Japan, but is not highly visible outside of Japan in radio hardware. NEC has partnerships with Netgear and Cisco/Ubiquisys, as well as core network integration relationships with Kineto, Tatara Systems, and Genband. NEC has successfully partnered with SpiderCloud to offer 3G/LTE and LTE-LAA solutions for the enterprise segment.
http://www.nec.com/en/global/solutions/nsp/sc/index.html

NOKIA:

Nokia's primary business focuses on infrastructure for the macro layer, but the company has jumped into the small cell game as well. They have announced small cell relationships with T-Mobile and Avantel (Colombia), but in general Nokia has been more successful in outdoor deployment than with indoor small cells. Nokia has integrated a Ruckus Wi-Fi AP into their indoor small cell product line, to fill out the critical need for unlicensed operation. With the completion of its Alcatel-Lucent acquisition, Nokia has rationalized its small cell portfolio. It has kept the residential/SOHO femtocell product line based on Qualcomm SoC. Its other indoor and outdoor small cells are based on its macro platform. With the common hardware and software stack, Nokia is able to scale up/down LTE features to address a wide range of small cell market segments from high-power outdoor units down to low power RRHs.
www.nokia.com

NXP (FREESCALE):

NXP has a small market share position in residential femtocells, and has developed a product line of high-end SoCs to support major OEMs for small cells. The QorIQ product line includes a proprietary DSP core approach and an efficient interconnect fabric to enable LTE, 3G, and 2G sniffing simultaneously for high capacity applications. Beyond its traditional stronghold in macrocell chipset market, particularly successful in the TD-LTE market in China, NXP found success in the small cell segment with design win in the Airvana OneCell socket. The merger with NXP has not had significant impact on the Freescale small cell SoC product line as the two companies do not appear to have large overlaps. However, with the pending acquisition of NXP by Qualcomm, Freescale/NXP small cell SoC line will likely be absorbed into Qualcomm's FSM product line. www.nxp.com

OCTASIC:

Octasic supplies DSP processors for small cells, and has a surprisingly high number of design wins for a small company. Octasic avoids competing with the big 'gorillas' in the industry by focusing on specialty markets including law enforcement, public safety, mining and oil exploration, and rural markets. www.octasic.com

OPENCELL:

OpenCell is a "small cells as a service" company based in the UK. It focuses on utilizing small cells to provide mobile coverage indoors, working closely with all major operators in the UK. www.opencell.co.uk

PARALLEL WIRELESS:

Since coming on the scene, Parallel Wireless has introduced several solution offerings targeted at different segments of the market. It has launched its distributed small cell architecture solution leveraging Intel SoC for small cells and HetNet Gateway to ease the deployment of LTE infrastructure. Its rural small cell deployment at EE, and HetNet Gateway solution for enterprise market has been well received in the market. More recently, it launched so-called "Band 14 in a box" to target public safety market, or more specifically FirstNet system in the US. The company has showcased many interesting use cases of both high-power and low-power small cells in rural/remote applications in the UK, Australia, and the US. www.parallelwireless.com

PHLUIDO:

This San Diego-based start-up is working to define and develop a virtualized radio stack based on split-baseband RRH architecture to alleviate high fronthaul requirements and costs associated with managing virtualized RAN. The company's "radio-as-a-service" solution emphasizes the key value proposition of running virtualized radio access network via less costly fronthaul links. The company has trials in Europe and in North America to help minimize the link costs between virtualized baseband data center and remote radio heads. www.phluido.net

QUALCOMM:

Qualcomm was late to the femtocell chipset market, but it has become the dominant chipset supplier to the small cell market. Since its acquisition of DesignArt, Qualcomm has been continuously investing in this segment to expand beyond its stronghold in handset market to small cell infrastructure. More recently, it has expanded its OEM partnerships with SpiderCloud, Samsung, and many others to expand into licensed, unlicensed and shared spectrum bands. By leveraging much of the research and development from the handset side, the company has been able to expeditiously and in close coordination, to introduce complementary small cell infrastructure SoC platforms, including new generation of small cell SoC that supports LTE-U/LAA and CBRS. www.qualcomm.com

RUCKUS WIRELESS (ACQUIRED BY ARRIS):

Ruckus Wireless uses adaptive antenna technology to deploy high-capacity, interference resistant Wi-Fi access points, and has focused on Wi-Fi offload for carriers such as PCW and KDDI. The company has partnered with Nokia for converged licensed/unlicensed small cells, and collaborated with Alcatel-Lucent on Licensed Wi-Fi Aggregation (LWA) which allows aggregation between LTE channels and Wi-Fi channels without forcing the LTE waveform into the Wi-Fi spectrum. Most recently, the company announced its OpenG technology initiative (based on 3.5 GHz CBRS) to provide cellular coverage and capacity indoors by leveraging shared spectrum for neutral host capable small cells. The company will find a new "home" after a series of merger announcements in the past year. Last year, Brocade, a networking company, acquired Ruckus as a part of its wireless strategy. A few months later, Broadcom announced its plan to acquire Brocade for Brocade's fiber channel storage area networking business. As a part of this complicated deal, Broadcom has agreed to sell Ruckus, and a part of Brocade's switching and routing business, to ARRIS. So, Ruckus will now be part of ARRIS, soon after the Broadcom-Brocade merger closes. www.ruckuswireless.com

SAMSUNG:

Samsung has deployed millions of CDMA femtocells in North America, with both Sprint and Verizon Wireless using the Samsung "UbiCell" for initial deployments. Samsung also supplied picocells for WiMAX networks, so they have easily converted to LTE small cell products, which have been selected by Sprint and a few other operators for ongoing LTE deployment. Most recently, Samsung has partnered with Qualcomm to support LTE-U/LAA capable femtocells. Samsung has been a key infrastructure supplier for Reliance Jio's LTE rollout and looks to expand its infrastructure business in North America with learnings from the Jio network buildout. Samsung has a portfolio of residential, enterprise, and carrier-grade small cells along with its macro product line used in the Jio rollout. www.samsung.com

SERCOMM:

Sercomm offers residential and enterprise small cells as well as Wi-Fi routers as a Taiwanese ODM. The company has taken the obvious step of integrating their Wi-Fi router and femtocell products together. Recently the company has focused on China and TD-LTE applications, and supplies TD-LTE, FDD-LTE, and dual-mode TD-SCDMA/TD-LTE small cells to that market. The company has also developed CBRS-capable small cell for the North American market. www.sercomm.com

SPIDERCLOUD WIRELESS (ACQUIRED BY CORNING):

SpiderCloud has been successful converting their field trial and early deployments into major customer wins with Vodafone, Verizon, and America Movil. The company is seen as a major player in the enterprise segment with expanding product features and spectrum bands, including LTE-U/LAA, CBRS, MulteFire, etc. The company is focused on enterprise networks, using a centralized controller to coordinate both Wi-Fi and licensed/unlicensed/shared LTE radio nodes. The company has established a key partnership with Cisco, where they work together to outfit the Cisco Wi-Fi APs in the field with "plug-in" modules, and also where Cisco sells the SpiderCloud solution for enterprise opportunities. The company was acquired in 2017 by Corning to supplement Corning's DAS business. www.spidercloud.com

TEXAS INSTRUMENTS:

TI's product lines support small cell deployment with integration of multicore baseband processors, as well as transceivers, ADCs and DACs, power over Ethernet, and other semiconductor functions. TI's strength in the KeyStone multi-core processor product line lies in small cells with relatively high capacity and functionality, running the same code as the macro base station in metrocells with multimode requirements. Of course, their existing relationships with Nokia and Ericsson come into play for "macro parity" small cells. TI's challenge in the high-end small cell market

lies in balancing the relatively low volume of the high-end metrocell market against the R&D investment to migrate to the next process node. www.ti.com

Xilinx:

Xilinx supplies field-programmable logic chips to the telecom industry for applications in baseband and radio equipment. The company has long held a leading market share position in macrocell radio processing, and as the incumbent supplier they have an opportunity to participate in CPRI and split-baseband RRH units. www.xilinx.com

ZTE:

ZTE offers a complete line of small cell products, and should be considered a major contender for the "nanocell" tender in late 2015. The company has been commercially shipping femtocells to Starhub in Singapore since 2009. The company also recently touted Qcell (DRS architecture) solution win at China Telecom. The ZTE product line is based on software-defined radios based on Texas Instruments SoCs which have the horsepower to run macro-level software for ideal coordination in a multimode HetNet. http://wwwen.zte.com.cn/en/products/wireless/small_cell/201407/t20140716_425767.html

8 ACRONYMS

2G: Second Generation Cellular

3G: Third Generation Cellular

3GPP: Third Generation Partnership Project

4G: Fourth Generation Cellular

5G NR: 5G New Radio, global 5G air interface standard

5GTF: 5G Technology Forum, a Verizon-led industry forum for 28/39GHz fixed wireless access trial and deployment)

ADC: Analog-to-Digital Converter

ARPU: Average Revenue Per User

ASIC: Application Specific Integrated Circuit

BBU: Baseband Unit

BSC: Base Station Controller

BSOC: Base Station on a Chip

BTS: Base Transceiver Station

Bits/Hz/sec: Digital bits transmitted per Hertz of bandwidth per second

CA: Carrier Aggregation

CAT-5: Category 5 Ethernet cable

CBRS: Citizens Broadband Radio Service, a shared wireless broadband use of the 3550-3700 MHz (3.5GHz) band in the US

CDMA: Code Domain Multiple Access, a 2G radio interface

CLEC: Competitive Local Exchange Carrier

CoMP: Coordinated MultiPoint

CPRI: Common Public Radio Interface, a non-profit organization and interface format

CPU: Central Processing Unit

DAC: Digital-to-Analog Converter

DAS: Distributed Antenna System

dBm: Decibels of power relative to 1mW

DSL: Digital Subscriber Line

DRS: Distributed Radio System

DSP: Digital Signal Processing or Digital Signal Processor

eICIC: Enhanced Inter-Cell Interference Coordination

eNB: e Node B, or the radio access node for LTE

EIRP: Effective Isotropic Radiated Power, an amount of power a radio transmitter and antenna radiates

ESC: Environmental Sensing Capability, applicable for 3.5 GHz CBRS, detects incumbent use of the 3.5 GHz shared spectrum

FDD: Frequency Division Duplexed

FPGA: Field Programmable Gate Array

GAA: General Authorized Access, applicable for the 3.5GHz CBRS, the lowest priority access, similar to unlicensed spectrum use

GB: Gigabyte

Gbps/km2: Gigabits per second per square kilometer

GGSN: Gateway GPRS Support Node

GHz: Gigahertz

GSM: Global System for Mobile communications, a 2G radio interface

GW: Gateway (normally referring to a femto gateway)

HetNet: Heterogeneous Network

HNB: Home Node B (femtocell)

HSPA: High Speed Packet Access

HSPA+: A subsequent evolution of HSPA with higher throughput

HVAC: Heating, Ventilation and Air Conditioning

Hz: Hertz (cycles per second)

IC: Integrated Circuit

IDAS: Indoor Distributed Antenna System

IMS: IP Multimedia Subsystem

IP: Intellectual Property

I/Q: In-phase/Quadrature modulation, a typical digital format for communications signal

I-ub: Interface standard for base stations

I-uh: Interface standard for femtocell to serving gateway

Km: Kilometer

Low-E: low-emissivity glass that inhibits heat transfer. As a consequence, cellular signal does not penetrate well outside in

LTE: Long Term Evolution, a "4G" radio interface based on orthogonal frequency division multiplexed data

LTE-A: LTE Advanced, a higher bandwidth version of LTE

LTE-LAA: LTE-License Assisted Access, a 3GPP-compliant LTE-U technology

LTE-U: LTE-Unlicensed, a technology to run LTE waveform on 5GHz unlicensed spectrum band

OBSAI: Open Base Station Architecture Initiative, a non-profit organization, and interface format

MAC: Media Access Control layer

MEA: Middle East and Africa

MHz: Megahertz

MIMO: Multiple Input, Multiple Output

MS: Mobile Station

mW: Milliwatt

OBSAI: Open Base Station Architecture Initiative

O-DAS: Outdoor Distributed Antenna System

OEM: Original Equipment Manufacturer

OFDM: Orthogonal Frequency Division Multiplexed

node B: A radio base station for WCDMA/HSPA

PAL: Priority Access License, applicable for the 3.5GHz CBRS

PB: Petabyte

PC: Personal Computer

PHY: Physical layer

QPSK: Quadrature Phase Shift Key

QAM: Quadrature Amplitude Modulation

QoS: Quality of Service

RAN: Radio Access Network

RF: Radio Frequency

RN: Relay Node

RNC: Radio Network Controller

RRH: Remote Radio Head

SAS: Spectrum Access System, to coordinate spectrum sharing in 3.5GHz CBRS

SCaaS: Small Cell as a Service

SGSN: Serving GPRS Support Node

SIP: Session Initiation Protocol

SNR: Signal-to-Noise Ratio

SoC: System on a Chip

TB: Terabyte

TD-LTE: Time Domain-based Long Term Evolution

TD-SCDMA: Time Domain Synchronous Code Domain Multiple Access

TV: Television

UE: User Equipment

VoLTE: Voice over LTE

VoWiFi: Voice over Wi-Fi (sometimes referred to as "WiFi calling")

W: Watts

W-CDMA: Wideband Code Domain Multiple Access, a 3G radio interface

Wi-Fi: Wireless Fidelity (802.11 data communications)

WiMAX: Worldwide Interoperability for Microwave Access (a "4G" standard)

9 METHODOLOGY

To create estimates and forecasts for small cell shipments and revenues, Mobile Experts relied on direct input from more than 60 industry sources, with 30 mobile operators contributing to the overall analysis to give a detailed global view of the market. Mobile Experts built a "top-down" forecast based on direct input from mobile operators and based on trends in end-user demand for mobile services. Then, Mobile Experts built a "bottom-up" forecast through discussions with the supply chain. Roughly 40 suppliers, integrators, and OEMs participated in this phase of the survey. Mobile Experts also used financial disclosures from publicly traded companies to assemble a quantitative view of the equipment market.

This year, Mobile Experts has changed the model framework to track four categories: Residential / Enterprise / Carrier Indoor / Carrier Outdoor. The previous category of Hi Power units are tracked under the Carrier Outdoor, but is tracked separately as a sub-category. Portions of the Distributed Radio Systems such as Radio Dot and LampSite are tracked under the Carrier Indoor and Carrier Outdoor segments.

The independent market for Carrier Wi-Fi is not included in this analysis, but integration of Wi-Fi into licensed-band small cells is considered. In this report, we cover the integration of unlicensed and licensed-band connectivity, and shed light on the prospects for specific LAA/Wi-Fi/CBRS integration options.

Figures 19 through 22 give the detailed definitions for each category of equipment, for regions of the world, for multimode vs. single mode, for frequency band categorization, and for small cells as a service categorization.

Definitions	RF Power	Backhaul	Architecture
Macrocell	30W+ composite	Operator managed	Closely controlled cells
Traditional Microcell	5.1-29W composite	Operator managed	RNC or BSC architecture (2G/3G)
Traditional Picocell	300 mW to 5W composite	Operator managed	RNC or BSC architecture (2G/3G)
Low power CPRI RRH	up to 1W per antenna	CPRI, OBSAI, ORI to separate baseband unit	No baseband processing in radio unit
Low Power Split-Baseband RRH	up to 1W per antenna	Proprietary format	Split baseband with scheduler in RRH and other baseband functions centralized
Carrier Outdoor (High Power) Small Cell	5.1W/ant-40W composite	Operator managed	Coordinated with macro layer, LTE or 3G gateway; some fixed wireless application
Carrier Outdoor (Low Power) Small Cell	300 mW to 5W per antenna. Below +52 dBm for mMIMO arrays	Operator managed	Coordinated with macro layer, LTE or 3G gateway
Carrier Indoor Small Cell	<300 mW per antenna	Operator managed	Lightly Coordinated with macro layer, LTE or 3G gateway
Distributed Radio System (DRS)	<300 mW per antenna	Operator managed	"Deeper" CRAN architecture where remote hub unit distribute IF signal to multiple radio units
Enterprise Small Cell	50 to 300 mW/antenna	Enterprise managed	Autonomous node (Gateway) or local controller.
Residential Femtocell	<50 mW/antenna	Consumer or SOHO managed	Autonomous node (Gateway)

Source: Mobile Experts

Figure 24. Detailed Definitions for each equipment category

North America:	USA and Canada
Latin America:	Mexico through South America, including Caribbean
Europe:	Western and Eastern Europe, including Russia
China:	China, including Tibet and Hong Kong
Asia Pacific:	India through Australia/Micronesia, excluding China
Middle East/Africa:	Pakistan and Turkey through Africa

Source: Mobile Experts

Figure 25. Detailed Definitions for regions

Multimode:	Capable of multiple simultaneous air interface standards (LTE, HSPA, GSM, etc.)
Adaptable:	Capable of one air interface standard at a time, but reprogrammable
Single-mode:	Capable of only one air interface standard

Source: Mobile Experts

Figure 26. Detailed Definitions for multimode/single mode

Multiband:	Capable of operating in multiple frequency bands, one at a time or simultaneously with separate baseband datastreams
Carrier Aggregation Units:	Units which operate in multiple bands with a single baseband datastream (inter-band CA)

Source: Mobile Experts

Figure 27. Detailed Definitions for multiband and carrier aggregation